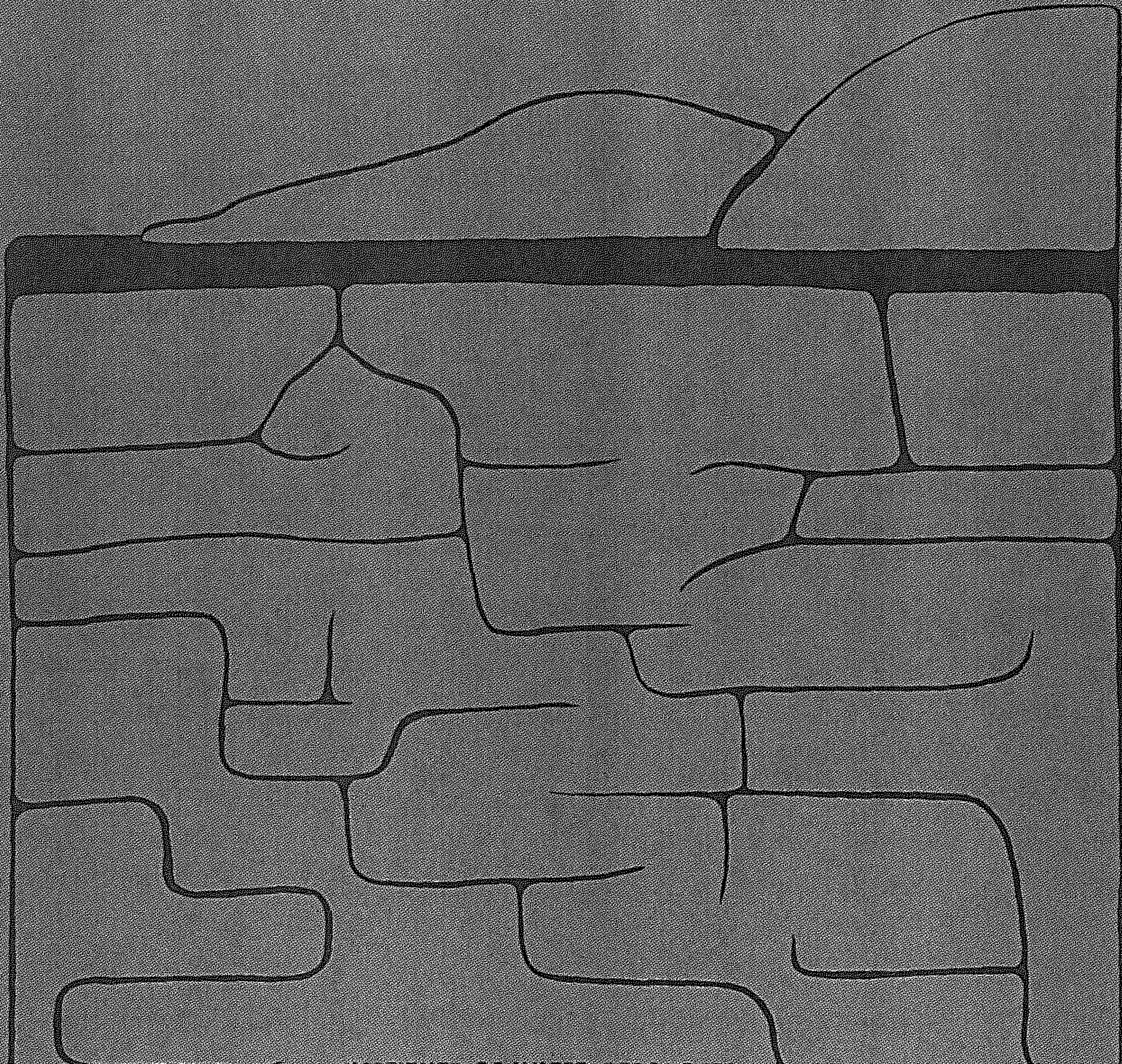
PRELIMINARY RESULTS ON THE STRUCTURE AND FUNCTIONING OF A TAIGA WATERSHED



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PRELIMINARY RESULTS ON THE STRUCTURE AND FUNCTIONING OF A TAIGA WATERSHED

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ABSTRACT

Comprehensive research in ecosystem functioning may logically be undertaken in the conceptual and physical context of complete drainage basins (watersheds or catchments). The watershed forms a fundamental, cohesive landscape unit in terms of water movement following initial receipt of precipitation. Water itself is a fundamental agent in energy flux, nutrient transport, and in plant and animal life. The Caribou-Poker Creeks Research Watershed is an interagency endeavor aimed at understanding hydrologic and, ultimately, ecological functioning in the subarctic taiga, the discontinuous permafrost uplands of central Alaska. Initial work includes acquisition and analysis of data on soils, vegetation, local climate, hydrology, and stream quality. Information acquired in the research watershed is summarized here, and implications for future data acquisition and research are considered.

ACKNOWLEDGMENTS

It will be virtually impossible to adequately acknowledge everyone who played an important role in establishing the Caribou-Poker Creeks Research Watershed and in the early studies there. In any listing, we run the risk of slighting by omission individuals who have contributed in one way or another. Given that warning, we would mention a number of people whose enthusiasm, support, and participation were crucial in this interagency endeavor: Mr. Walt Duncan, U.S. Army Corps of Engineers (retired); Mr. Glenn Audsley, U.S. National Weather Service; Mr. Tom Bowers, U.S. National Weather Service; Dr. Max Kohler, U.S. National Weather Service (retired); Dr. Eugene Peck, U.S. National Weather Service; Mr. Ted Freeman, U.S. Soil Conservation Service; Dr. Edward Berry, U.S. EPA (retired); Dr. Bonita Neiland, University of Alaska; Mr. William Quirk, formerly with the University of Alaska; Dr. Douglas Kane, University of Alaska (formerly with USA CRREL); Dr. Charles Cushwa, U.S. Forest Service; Dr. C. T. Dyrness, Institute of Northern Forestry, U.S. Forest Service; Mr. Richard Latimer, U.S. EPA; Mr. Ernst Mueller, U.S. EPA; Dr. Jerry Brown, USA CRREL; Mr. Ed Clark, USA CRREL (retired); Mr. James Meckle, U.S. Geological Survey. Technicians whose principal duties were with the research watershed, and whose work was indispensable to the program, have included Mr. R. "Spike" Arnold, Mr. Steve Jordan, Mr. Eugene Culp, Mr. James Gilchrist, Mr. Pat Quinn, Mr. T. Winston Hobgood. Special acknowledgement and thanks are due Mr. Austin Helmers, Institute of Northern Forestry, U.S. Forest Service (retired). Austin's enthusiasm and active field work have been invaluable over the years. Helmers' Ridge in the research watershed, is fittingly named as it is a high point in the basin, just as Austin has been a high point in our personal and professional affiliations.

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INTRODUCTION

Watersheds act as integrators of hydrologic processes. Water yields from a basin reflect this integration. When the interrelationships of process and landscape are understood, land managers can predict and assess results of "good" or "bad" management practices. Although all watersheds may have some features in common, such as input of precipitation and outflow of water, each reflects a unique combination of controlling factors and processes. It is only through research designed to describe, interpret, and understand these processes that watershed managers can utilize these natural entities for maximum benefits without environmental damage. Since watersheds are interactions of life with environment, watersheds can be considered ecosystems and effectively studied within this unifying concept.

In the broadest context, each watershed is part of the biosphere, consisting of land, water, and air--the life support system as we know it. Mankind as an individual species is increasingly affecting this system through growing populations that require more intensive extraction of resources. It is in part because of this increasing pressure on resources that watershed functioning must be understood, if catchments are to be managed to take advantage of each basin's capabilities to provide for the needs of mankind.

As resources become scarce in other regions, and renewable and nonrenewable resources of the North become more valuable, watersheds in the subarctic will be subjected to new and increased pressures. Research must be initiated to evaluate subarctic watersheds in terms of the unique environmental factors caused by cold climate and low precipitation. To our knowledge, only one long-term comprehensive program of research on high latitude watersheds is underway in North America. Established in 1969 by the Inter-Agency Technical Committee for Alaska,* the Caribou-Poker Creeks Research Watershed serves both our need for baseline data acquisition and a site for study of specific hydrologic and environmental processes. This paper develops the rationale for implementing a subarctic research watershed program and summarizes completed and ongoing work in Caribou-Poker Creeks Research Watershed concerning hydrologic regimen, meso-climate relationships, site characterization, and baseline water quality patterns.

DATA NEEDS

The North American subarctic coincides with the region of discontinuous permafrost (Figure 1). There has been little study of hydrologic parameters and processes in this region, and even less on a watershed basis. Dingman's (1966, 1971) work on a 1.8 km^2 catchment

* Now designated the Inter-Agency Hydrology Committee for Alaska.

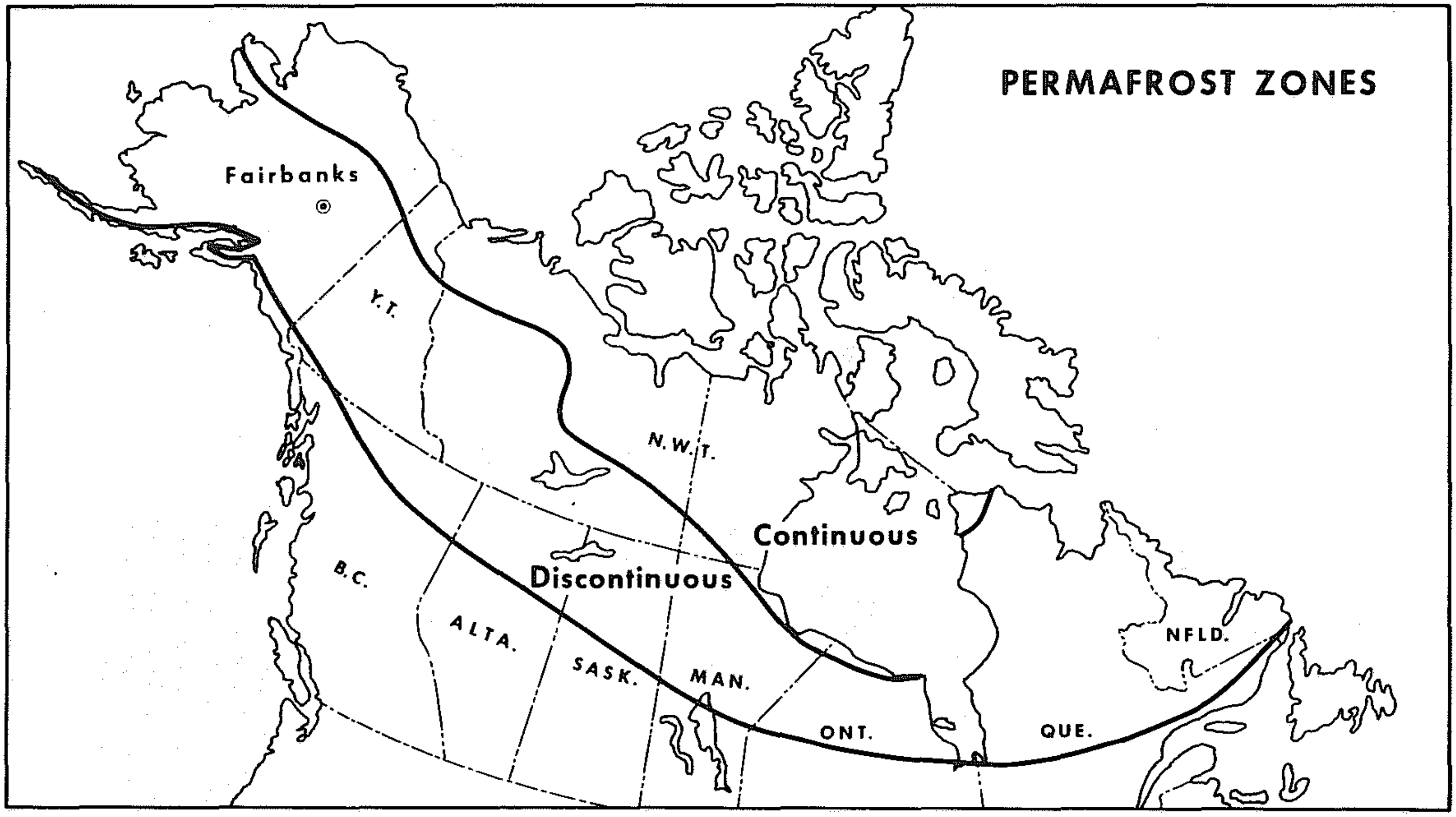

Figure 1. Distribution of permafrost in North America. Note that Fairbanks, which is near the Caribou-Poker Creeks Research Watershed, is almost in the middle of the zone of discontinuous permafrost.

near Fairbanks was the first "watershed" study in subarctic Alaska. Until recently, subarctic environmental research has been conducted along narrow disciplinary lines.

At the same time, basic hydrologic and environmental data are spare in subarctic Alaska (Feulner el al., 1971; Hare, 1971; Slaughter et al., 1974; and Hartman and Johnson, 1978). Basic information (such as precipitation and runoff data for upland areas) is lacking due to the low population of the subarctic, the logistical problems of data gathering, the high cost of operations in remote, severe environments, and (until recently) a lack of obvious need for information on this part of the continent.

The need for environmental data, including water resources information, is now apparent. The prolonged debate over the completed trans-Alaska oil pipeline emphasized the information gap in the subarctic. A major shift in land control is currently taking place with settlement of the Alaska Native land claims. Some 18 million hectares will change hands in Alaska within the next several years; at least fifteen new national forests, parks, wildlife refuges, wild and scenic rivers, and ecological reserves have been proposed for Alaska's subarctic.

These developments presage changes in resource management alternatives and needs. All accentuate the need for both baseline environmental data and, more significantly, for developing the operational capability to assess immediate and long-term environmental consequences of land management practices.

Pressing information needs notwithstanding, much has been accomplished. Existing environmental and hydrologic data have been summarized on a statewide basis by Hartman and Johnson (1978) and Feulner et al. (1971). Forest environment research in interior Alaska was initiated at the Institute of Northern Forestry (USDA Forest Service) in 1957. The University of Alaska's Institute of Water Resources is building a statewide hydrologic research program. Federal hydrologic programs have also been recently accelerated in some sectors (e.g., Brice, 1971; Childers et al., 1973).

RATIONALE FOR WATERSHED RESEARCH, AND EXAMPLES FROM OTHER SETTINGS

A "watershed" is a landscape unit encompassing a complete stream drainage system and is equivalent to a catchment or drainage basin. The "research watershed" concept includes both representative and experimental basins, as defined by Toebes and Ouryvaev (1970). "Representative basins are selected as characteristic of a hydrological region, i.e., a region within which hydrological similarity is presumed. They are used for intensive investigations of specific problems of the hydrological cycle under relatively stable, natural conditions. Experimental basins are relatively homogeneous in soil and vegetation, and have uniform physical characteristics. They are deliberately modified and the effects of these modifications on the hydrological characteristics are studied."

There are areas of overlap and complementary function between these types. For example, an undisturbed representative basin could be used as the control for an experimental basin landscape treatment.

Watershed management is defined as management of land for the optimum production of high-quality water, regulation of yields, and for maximum soil stability along with other products of the land. While water is the primary concern and unifying medium for this discipline, the increasing trend is to treat watersheds as systems to be managed for a wide range of possible uses. A wide range of resource management activities necessarily bears on rational watershed management. It follows that watershed research encompasses a similarly broad field. Some aspects of research into almost all facets of wildlands and natural resources--from forest pathology to logging engineering and wildland recreation--have direct bearing on hydrologic functioning of natural landscape units. The quality, quantity, or timing of water yield, and the onsite or offsite benefits derived from the watershed, also often have complex interrelationships with the larger plant and animal community, including man. Water quality and hydrologic regimen are often reliable indicators of the overall environmental health of a landscape.

Watershed-based research has dealt with a wide variety of water-related problems. Several symposium summaries (Sopper and Lull, 1967; American Society of Civil Engineers, 1970; ISAH-UNESCO, 1970; New Zealand Hydrological Society, 1970; Csallany et al., 1972) provide examples of catchment-based research dealing with or applicable to topics such as precipitation relationships, soil moisture, groundwater, seasonal snowpack hydrology, vegetation-water yield interactions, water quality, erosion, site restoration, wildlife habitat management, and various relationships of vegetation treatment to hydrologic response.

Wider questions of interactions between land use and hydrologic response have been approached in the context of research watersheds in many regions, including Japan (Nakano, 1967), South Africa (Periera, 1973), the Soviet Union (Kuznetsov et al., 1969), and Scandinavia (Hogstrom and Larsson, 1968; Falkenmark, 1973; Swedish National Committee for the IHD, 1974). Dils (1957) stressed a broad role for Coweeta (North Carolina) watershed research in integrated land, water, and vegetation management. Describing the rationale for establishment of the East Slopes (Alberta) Watershed Research Program, Jeffrey (1964) stressed that objectives included both hydrologic studies and analysis of interrelationships between water and other ecosystem factors. In New Zealand, a comprehensive system of representative basins was established to provide information for both short-term and long-term solutions to problems of past, present, and anticipated changes in land use and management (Ministry of Works, 1970). To cite a more current example, in the Bitterroot National Forest of Montana (scene of a recent debate on forest management practices), Bateridge (1974) employed paired catchments to study hydrologic effects of clear-cutting and road development on forest lands.

Progress in watershed studies over the past several decades has coincided with increasing awareness of the far-reaching consequences of many human activities on land and water resources. Both popular and scientific interest in ecosystem functioning and in rational resource management is increasing.

Many scientists and agencies respond to environmental questions by emphasizing ecological research, often stressing a systems approach (Dale, 1970). A consequent strong emphasis has been placed on inventorying specific ecosystem components, defining and understanding interchanges, pathways, and rates of nutrient, energy, and mass flow or cycling. For instance, Reichle (1970), in Analysis of Temperate Ecosystems, emphasizes the study of specific ecosystem components and processes. Also in that book, Stanhill (1970) considers the hydrologic cycle in some detail, while Curlin (1970) discusses hydrologic models and stresses that the hydrologic cycle and the chemical cycles operating in a watershed ecosystem are inseparable.

Odum (1969), discussing ecosystem development and eutrophication of natural water bodies, noted that it is the entire drainage or catchment basin (not just the lake or stream) that must be considered the ecosystem unit if we are to deal successfully with our water pollution problems. It is proving surprisingly difficult to get tradition-bound scientists and granting agencies to look beyond their specialties toward the support of functional studies of large units of landscape. Major (1969), in discussing the development of the ecosystem concept, stated that a watershed is an ecosystem subject to multiple use, while Cooper (1969) defined a watershed as almost a rewording of the classic definition of an ecosystem. As such, a catchment of convenient size is useful for studying interactions among plants and animals and their nonliving environment. Thus, we have three eminent ecologists referring to watersheds as ecosystems. Hydrology--the science that treats the waters of the earth, their occurrence, circulation, and distribution, their chemical and physical properties, and their reaction with their environment, including their relation to living things (Chow, 1964)--could well be the integrating science to coordinate interdisciplinary effort in ecosystem study.

Nelson (1970) emphasized output sampling from research catchments in terms of dissolved and particulate load, and cited an English catchment study indicating significant nitrogen loss through erosion of peat from a moorland catchment. He said that "small watersheds are ideally suited for studies of the effect of cultural activities on the landscape or mineral movement from land into water. While it may be convenient to consider terrestrial and aquatic habitats separately, they are inextricably related, and effective models of ecosystems must consider the relationship. Minor element budgets developed from catchment basin study areas will be useful for testing hypotheses relating the effect of land management practices on water quality in streams."

Nutrient and water relationships were recognized from the outset in what has possibly been the most highly visible analysis of nutrient cycling in forest ecosystems--the studies at Hubbard Brook Experimental

Forest in New Hampshire (Bormann and Likens, 1967; Likens et al., 1967). The broad objectives of the Hubbard Brook Ecosystem Study were to determine effects of forest cutting and herbicide treatment on water yield and chemical relationships within the ecosystem (Johnson et al., 1969). They also emphasized that the nutrient cycle is closely connected to the water cycle; precipitation brings in nutrients, water leaches them from rocks and soil, and streamflow carries them away (Bormann and Likens, 1970).

Hubbard Brook was not, of course, the only scene of recent watershed nutrient cycling research. In Maryland, Cleaves et al. (1970) studied the geochemical balance of a forested catchment; Fredriksen (1972) and Grier et al. (1974) analyzed nutrient relationships of a Douglas fir forest watershed in western Oregon. In western Washington, Olsen and Chapman (1972) reported on ecosystem research in the Fern Lake watershed, observing that a watershed offers a natural and convenient unit for such analyses. Ryan et al. (1974) applied ecosystem modeling and management "gaming" to a complete Washington river basin. They noted that water is a common link between most of the processes occurring within the forest ecosystem. The reaction of the hydrologic system to manipulations of the forest ecosystem is a major concern in the general simulation model. Johnson and Swank (1973) studied nutrient movement within and through southeast U.S. watershed systems, and cited advantages of the existing Coweeta site for their work. Such advantages included the 35-year history of hydrologic and climatological monitoring, a well-documented history of the vegetation of the watersheds, and a variety of experimental manipulations designed for water yield improvment studies.

Huff (1971) dealt directly with these hydrology-ecology interactions. His study of ecosystem hydrology focused on the effects of hydrologic processes and conditions on ecosystems, and the effects that ecosystems exert on hydrologic processes. The work of Huff et al. (1970) stressed this hydrology-ecology interplay in adapting the Stanford Watershed Model (Crawford and Linsley, 1966) for simulation of movement of nutrients through the land-lake system of Lake Wingra, Wisconsin.

Such multidisciplinary studies provide a readily available base of hydrologic, climatologic and site characterization data for the research areas, along with a documented history of vegetation development or treatment. Simple economy of effort can be a strong argument for cooperation; in regions where environmental data are scarce and field operations expensive, mutual efforts in data acquisition and logistics can be most attractive. A less tangible, but nonetheless important aspect of cooperation, is the "broadening of horizons" for investigators of all disciplines that comes from association with specialists in fields other than one's own (Helmers and Cushwa, 1973).

STUDY AREA

In response to the data needs cited previously and an opportunity for interdisciplinary water-related research in central Alaska, the Caribou-Poker Creeks Research Watershed was established in 1969. The

104 km^2 catchment was selected because it is reasonably representative of the Yukon-Tanana Uplands, a major physiographic unit of subarctic central Alaska and adjacent Canada, and because it is an environment subject to increasingly active resource exploitation and management.

The composite Caribou-Poker creeks drainage (Figure 2) is at $65^{o}12'$N, $147^{o}39'$W, less than 3^{o} south of the Arctic Circle. Caribou Creek and Poker Creek meet at a point approximately 1.5 km from the southern catchment boundary; the joined stream, Poker Creek, is a tributary to the southwesterly flowing Chatanika River, in turn tributary to the Tanana and Yukon rivers. The entire watershed is depicted within the Livengood A-1 and A-2 Quadrangles, U.S. Geological Survey 1:63,360 scale topographic maps. Figure 3 is a general view of the watershed with Poker Creek on the right edge; Caribou Peak is at right center.

Elevations range from 210 m in the lower valley, to 774 m on Caribou Peak, near the center of the basin (Figure 3); the maximum elevation of the watershed is 826 m, at a point on the northeastern boundary. Valley floor elevations at the headwaters (intersection of the uppermost tributaries) of Caribou and Poker Creeks are 328 m and 360 m, respectively.

The general geologic setting of the research watershed has been described by Koutz and Slaughter (1972). The catchment is in the Yukon-Tanana Uplands (Wahrhaftig, 1965) in terrain underlain by metamorphic Precambrian Birch Creek Schist. The dominant structural trend of the meta-sedimentary basement complex in the vicinity of Caribou-Poker creeks is northeast. Mineralization in the catchment is limited, as indicated by the absence of active or abandoned mining works and lack of assessment work on the few placer claims filed in the basin between 1902 and 1937. Chatanika River appears to include a zone of disconformity marking the northern edge of thrust faulting that preceded mineralization (Florence Weber, personal communication); this may explain the absence of metal north of the river. The Chatanika River valley has been intensively dredged for gold immediately downstream from the mouth of Poker Creek.

The bedrock schists are mantled with Quaternary wind-blown silts (loess) of varying thickness (commonly less than a meter). These silts are largely derived from the flood plains of rivers flowing north from the Alaska Range, and vary in age from Illinoian through Wisconsin to recent (present).

Perennially frozen silts in valley bottoms contain large quantities of partially decomposed organic material. Such deposits are locally termed muck, because of their thixotropic behavior and characteristic decaying odor when thawed. Such organics and organic silts can have a significant effect on quality of groundwater, affecting taste, color, odor, pH, and oxygen demand when thawed (Cederstrom, 1963). Such deposits are found in the lower reaches of Caribou Creek and Poker Creek valleys.

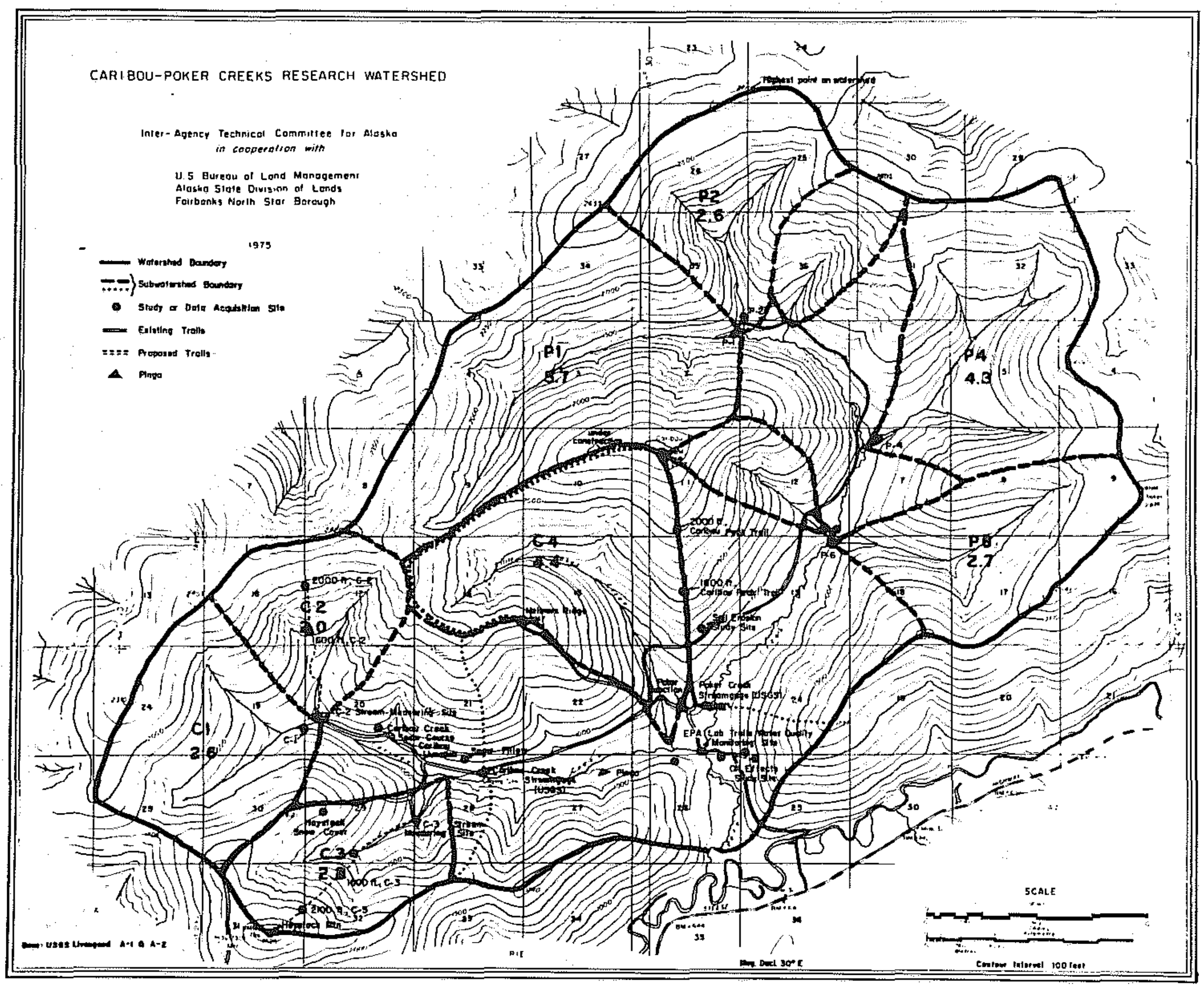

Figure 2. Topographic map of the research watershed showing subdrainage and size (in square miles) of each (note that Caribou Peak is near the geographic center of the watershed).

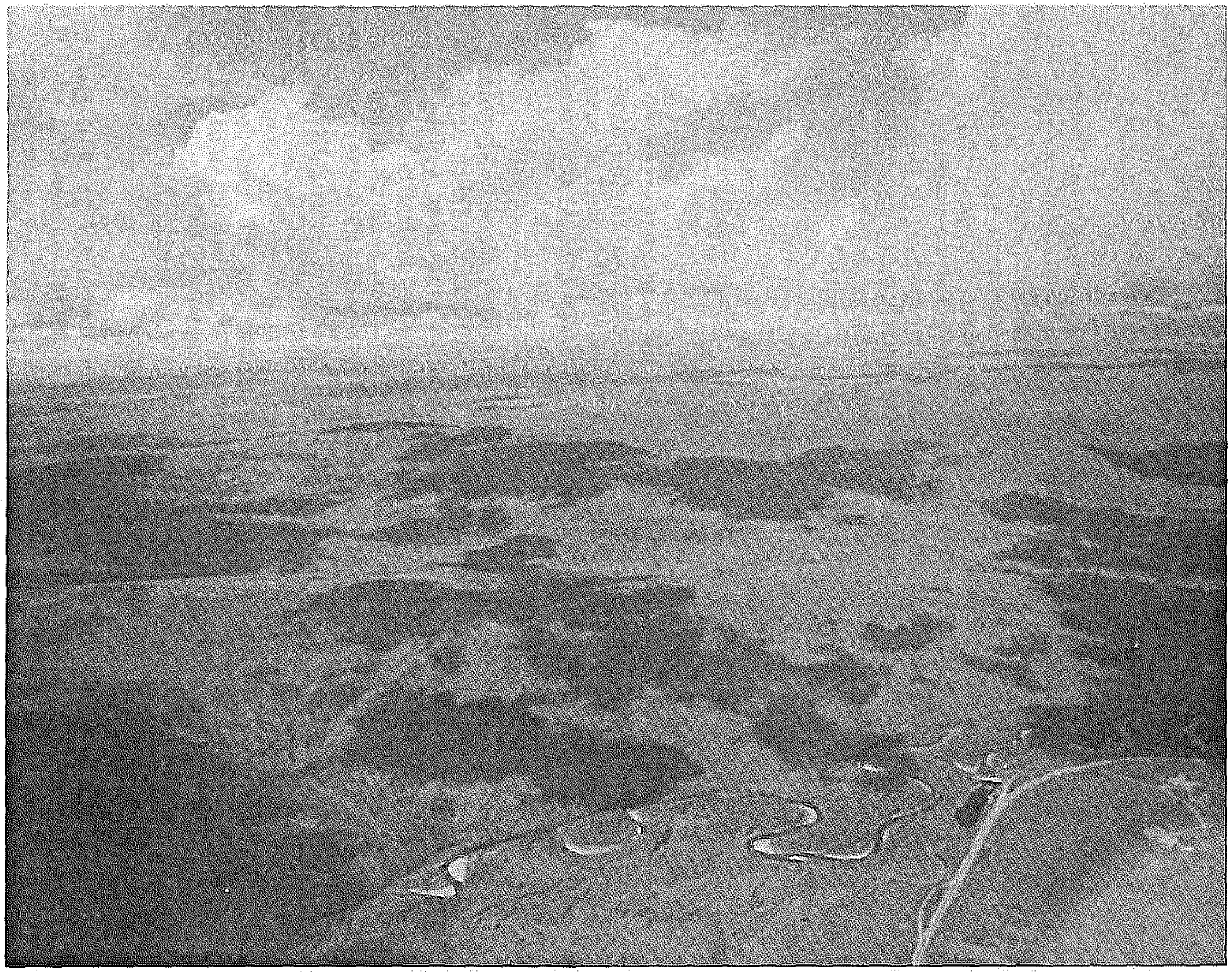

Figure 3. High-level photo of Caribou Basin with Caribou Peak at right center. All subdrainages are visible in this view looking nearly due north.

The surficial deposits have gradational contacts with the underlying weathered schist. Rock outcrops, while not common, are found primarily on ridges at higher elevations. Rieger et al. (1972) noted that bedrock is found less than a meter below ground surface over much of the upland area of the watershed. Past (and possibly current) periglacial activity is evidenced by presence of solifluction lobes, subdued block fields, tors, and slumps on north-facing slopes. This sector of the Yukon-Tanana Uplands was not glaciated during the Pleistocene.

The streams and valleys of this catchment comprise a typically dendritic drainage pattern. Caribou Creek is a second order stream, whereas Poker Creek is a third order stream (Strahler, 1957). Stream channels are typically steep walled and narrow (1-2 m) in subdrainages. In the main valleys, wider channels (2-4 m) are encountered. While alternating pool-and-riffle conditions are common, fairly vertical to undercut stream banks remain dominant. Vegetation generally overhangs stream channels (Figure 4). Streambeds are predominantly sand and gravel, although cobbles and boulders are encountered increasingly in upstream channels of tributary streams.

WATERSHED CHARACTERIZATION

PHYSICAL PARAMETERS

Physical and geomorphic parameters may be used to characterize a landscape or drainage basin. Eight such factors are listed in Table 1, with values given for the entire watershed and for individual subdrainages. All parameters were measured on standard USGS topographic sheets, at a scale of 1:63,360.

Total area drained by Poker Creek (a third order stream; Strahler, 1957) is 59.8 km^2 while 41.7 km^2 is drained by Caribou Creek (a second order stream). Clearly defined subbasins range in size from 4.9 km^2 (C-2) to 14.7 km^2 (P-1). Figure 2 shows the designation and outline of each subbasin. Only one subbasin in the Caribou Creek watershed has a second order stream (C-1), whereas the Poker Creek watershed has two basins (P-2 and P-4) with second order streams. This probably reflects the somewhat larger areas of the subbasins in Poker Creek.

Aspect, the general orientation of a catchment, is an important property that partially controls solar insolation received by a basin. This watershed complex contains two basins (C-2 and P-2) with a dominant south aspect and many slopes that are dominantly southern. All other subbasins have some slopes with a northerly exposure.

Four subbasins have their lowest elevations above 300 m: C-1 and C-2 (337 m), and P-1 and P-2 (358 m). Caribou Peak (elevation 770 m), near the center of the watershed complex, is less than 60 m lower than the maximum elevation in the entire catchment, making it an ideal high-elevation climatological site for the watershed as a whole. Helmers' Ridge (at elevation 627 m, east of C-2 and south of C-4) offers another attractive site for climatological measurements.

Figure 4. View of one of the small streams draining a subdrainage; note the steep gradient and overhanging riparian vegetation.

Compaction coefficient (CC) provides a measure of the shape of a particular basin; it is defined as the perimeter length of a watershed divided by the circumference of a circle with the same area. By this definition, a circular basin will have CC of 1.0, whereas a long narrow basin will have a much higher value. Shape of basins becomes important when considering hydrologic response time and yield of a particular storm event where various shapes and orientations of basins are involved. Using CC as an indication (see Table 1), the Caribou Creek drainage basin is much more compact than is the Poker Creek basin. The higher value for Poker Creek is clearly influenced by the linear upper reaches of subdrainage P-1. Subbasin C-2 (CC = 1.08) and subbasin C-3 (CC = 1.10) have the most compact shape. Basins C-1 and P-2 have identical compactness (CC = 1.14), and similar elevation and size. Subbasins P-1 and C-4 have similarly high compaction coefficients (1.24 and 1.25, respectively). This reflects their greater linearity compared to the other subbasins. Subdrainages P-4 and P-6 have identical compaction coefficients (1.20), although P-4 is much larger and has a dominantly SW aspect compared to the NW aspect of P-6.

Drainage density, the ratio of total stream length to basin area, is less than 0.6 km/km^2 for all subdrainages except P-4; that subbasin has a drainage density of 0.7 km/km^2. These drainage density values are much lower than those cited for similar basins in temperate latitudes (Leopold et al., 1964). Dingman (1971) found similarly low drainage densities in a variety of central Alaska basins. He gives five reasons why drainage densities are so much lower in interior Alaska: low intensity precipitation; low amounts of precipitation; highly absorptive moss layer; spring runoff over frozen ground with thick litter layer; and permeable soil after thawing of the active layer (on permafrost sites). Bredthauer and Hoch (in press) utilized extremely detailed drainage network mapping of Caribou-Poker creeks, and reported drainage densities in the range 1.35-5.34 km/km^2. Their techniques were not those normally used in positive hydrologic analysis, but may be relevant to detailed geomorphic research.

Area-elevation relationships, summarized in Table 1, are relevant when comparing precipitation/runoff behavior of individual basins, because of potential orographic effects on precipitation. Considering the entire watershed, 8.2% of the area is below 303 m (1000 ft) elevation; zones of 303-485 m and 485-637 m each account for about 33%, while 24% of the watershed is above 637 m elevation. The Poker Creek basin is generally higher than Caribou Creek; 69% of the Poker Creek drainage is above 485 m compared to 45% for the Caribou Creek basin. Considering Caribou Creek subdrainages, only C-4 has an appreciable area (5.9%) below 303 m, whereas only C-2 has a major area (33%) above 627 m elevation. In Poker Creek, on the other hand, both P-1 and P-2 have 53% and 62% of their respective areas higher than 637 m elevation.

The last column of Table 1 shows the proportion of permafrost area for each basin and subbasin; areas were determined by planimeter from the soils map (Rieger et al., 1972) and are approximations based on soil boundaries. Of the total basin area, 31% is underlain by permafrost; 30% of the Poker Creek drainage is underlain by permafrost, compared to 28% for the Caribou Creek basin. This difference probably reflects the

TABLE 1. SOME PHYSICAL HYDROLOGIC CHARACTERISTICS OF CARIBOU-POKER CREEKS RESEARCH WATERSHED.

Basin	[1]Area km²	Aspect	Elev. m	[2]Comp. Coeff.	[3]Total Stream	[4]Drainage Density	[5]Area Elevations % 305m	305-488	488-640	640	[6]8%
P-C	101.5	—	226-826	1.19	48.4	0.77	8.2%	34.2%	32.5%	24.1%	30.7
PM	59.8	S	226-826	1.31	29.6	0.80	7.8	31.3	33.5	25.9	30.5
CM	41.7	E	226-770	1.08	19.0	0.73	9.8	39.9	23.8	21.5	28.0
C1	6.7	E	329-738	1.14	3.5	0.86	0.0	40.8	43.4	15.8	26.1
C2	5.2	S	329-738	1.08	2.2	0.70	0.0	29.0	38.0	33.0	3.5
C3	5.7	NE	274-770	1.10	2.6	0.73	0.1	39.5	51.4	9.1	53.2
C4	11.4	SSE	226-686	1.24	5.0	0.70	5.9	27.3	50.9	15.9	18.8
P1	14.8	ENE	360-869	1.25	5.8	0.63	0.0	15.8	34.3	52.8	37.8
P2	6.7	S	360-826	1.14	4.0	0.96	0.0	10.0	16.9	62.0	6.9
P4	11.1	SW	293-825	1.20	7.7	1.11	0.1	41.4	30.5	27.5	14.2
P6	7.0	NW	271-755	1.20	3.9	0.89	0.2	37.1	42.7	18.5	17.8

1 From Slaughter (1971) includes that area above Caribou-Poker confluence.
2 Compactness Coefficient = perimeter, divided by circumference of circle of equal area.
3 From USGS topog. map.
4 km per km², from 1:63, 360 scale topog. maps.
5 From USGS topog. map.
6 From soils map, Reiger et al. (1972).

slightly higher elevation and greater area of north-facing slopes in Poker Creek. Individual basins exhibit a wide range in permafrost area, from a low of 3% for C-2 (a south-facing basin) to 53% for C-3 (north facing). P-1 has 38% of its area underlain by permafrost. P-2 is similar to C-2 in aspect, size and compaction coefficient. It is also low in total area underlain by permafrost (7%), even though 62% of its area is above 637 m elevation. This probably reflects the influence of its southerly aspect, which permits a higher total insolation to offset the effects of higher elevation. Other basins range from 26% (P-1) to 14% (P-4) permafrost.

SOILS

Soils of the watershed are poorly developed; textures within the profile range from silts to gravels, with a thin layer of loess comprising the surface few centimeters (Rieger et al., 1972). Seven soil series are recognized in the watershed (Figure 5); some have several slope phases. All series are classed as silt loams, although each may contain various quantities of sands or gravels, and all are medium to strongly acidic. Two series are derived from alluvium: the Bradway series, occupying the major floodplains; and the Karshner, occupying narrow floodplains of smaller streams. Both series have shallow permafrost. All other series are derived from bedrock at varying depths with admixture of loess. Two of these soils, Ester silt loam on north-facing slopes and Saulich silt loam at the foot of slopes, are underlain by permafrost. The remaining three series are generally free of permafrost, with the Fairplay series occupying ridgetops and the closely similar Olnes and Gilmore series occupying southerly slopes. Both are well drained, with Olnes deeper over shattered bedrock.

Comparing the soils of the Caribou-Poker creeks watershed with those of the Fairbanks area, some 45 km to the south, suggests that several series (Ester, Gilmore, Saulich, and Bradway) occur in similar positions in both areas. Two deep silty soils appearing on the Fairbanks map (Fairbanks and Minto silt loams) are entirely missing in Caribou-Poker creeks. This absence reflects the distance from the source of loess material between the two areas of deposition. The mantle of silt is believed to have its origin in the glacial outwash plains south of Tanana River (Pewe, 1955). The silts near Fairbanks are thick (up to 5+ m), whereas the same deposits become much thinner 40 to 50 km to the north, thus eliminating both the Fairbanks and Minto series in the narrow valleys of Caribou-Poker creeks.

In summary: 1) all soils are poorly developed with a thin cover of loess, 2) all are thin with gravel or shattered bedrock within a few to 50 cm of the surface, 3) pH is low, being acidic to strongly acidic, 4) although texturally classed as silt loams, all series are relatively high in sand or gravel content according to profile descriptions, 5) more than two-thirds of the watershed complex is occupied by permafrost-free soils, 6) soils lacking permafrost are moderately well-drained.

The preceding discussion explained how two of the five soil-forming factors, parent material and topography, influence the soil pattern and properties of the Caribou-Poker Creeks Research Watershed. The next

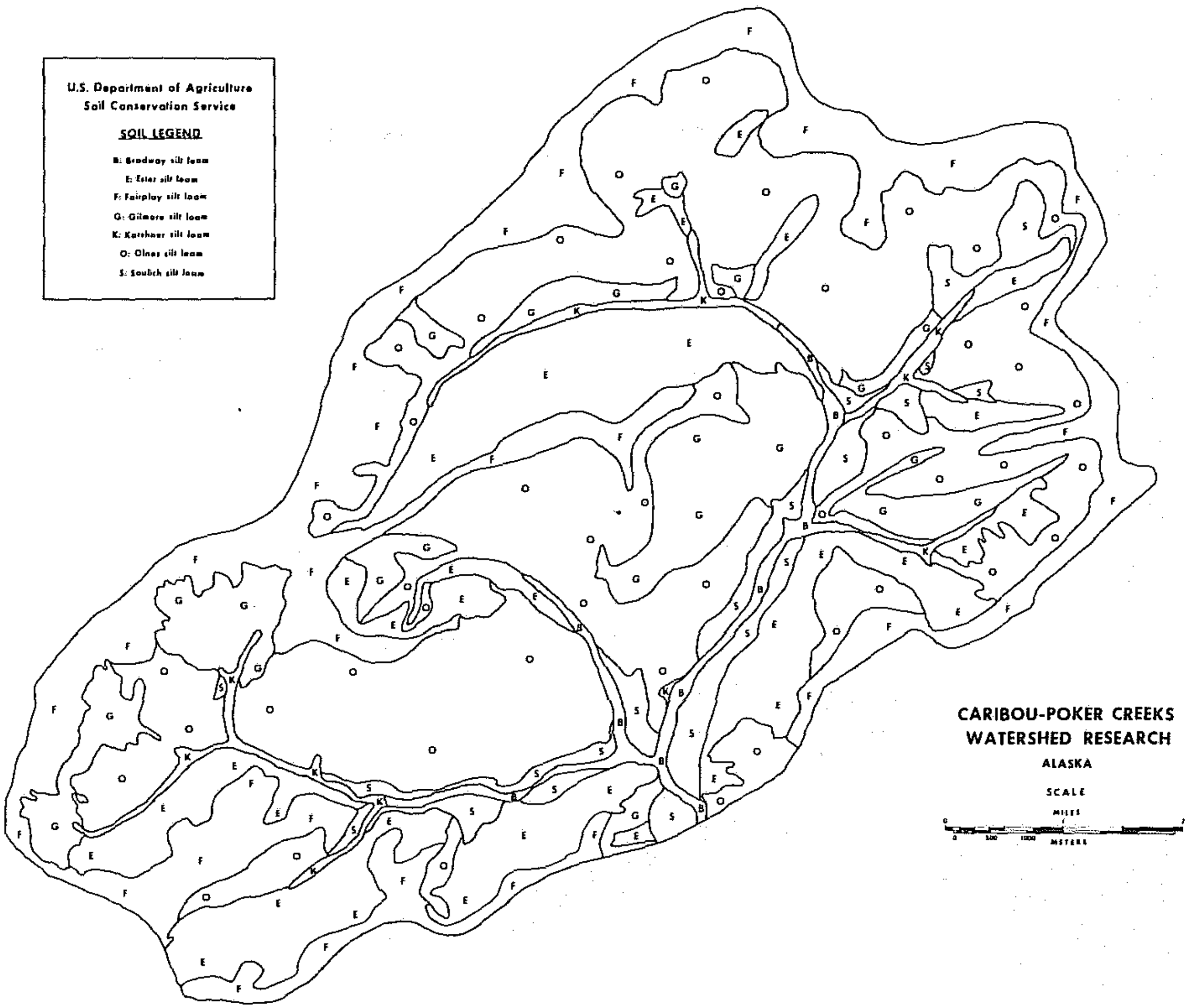

Figure 5. Soils map of the watershed. Only major units are shown (series are without slope classes to simplify the map).

section describes vegetation patterns, relates distribution to soil pattern, and describes how vegetation interrelates with other soil forming factors to impart physical and chemical properties to the watershed soils.

VEGETATION

Vegetation is an important element in most environments. Knowledge of plant ecology is fundamental in assessing the response of a watershed to changing climatic patterns or man-induced perturbations. The composition and pattern of vegetation is the result of several interacting elements including geology, soils, local and regional climate, land form and (especially in central Alaska) fire history.

The Caribou-Poker creeks catchment lies within Spetzman's (1963) "moderately high mixed evergreen and deciduous forest" cover type. This he described as a "moderately tall, dense, forest of evergreen and deciduous trees; composed of white spruce, black spruce, quaking aspen, balsam poplar, and white birch in various combinations. In general, trees are 6 to 15 m high, 15 to 30 cm in diameter, have shallow roots and are commonly spaced 2 to 3 m apart. White spruce ranges from 12 to 24 m in height and 20 to 40 cm in diameter, has a dense, narrow, pointed crown, and a straight trunk branched almost to the ground, forms pure stands along streams and grows with scattered birch or aspen on moderate slopes. Black spruce ranges from 5 to 12 m in height, and 8 to 15 cm in diameter, has a narrow pointed crown of short stiff branches, forms pure stands on north facing slopes and poorly drained flat areas. Aspen ranges 6 to 15 m in height, and 8 to 30 cm in diameter, has a long, bare white trunk, and open crown, grows generally following forest fires in pure or mixed stands on well-drained soils. White birch ranges from 9 to 18 m in height and 15 to 30 cm in diameter, grows in clumps, usually mixed with white spruce on rocky slopes, and in very dense stands with aspen on burned slopes. Balsam poplar ranges from about 12 to 15 m in height, and 30 to 60 cm in diameter, has a long bare trunk and deep roots, occurs in small scattered groves along streams. Locally common are burn scars, with regrowth of fireweed, tall grass, willow brush 3 to 6 m high, and small trees. Undergrowth and ground cover highly varied, consisting of thick spongy moss and low brush on cool moist slopes, grass on dry slopes, and dense brush of willow, alder, and dwarf birch 1.5 to 3 m high in open forests near tree line."

On the more recent map of major ecosystems of Alaska (Alaska Land Use Planning Commission, 1973), the research watershed falls entirely within the category of upland spruce-hardwood forest. This community is represented by a fairly dense interior forest composed of white spruce, birch, aspen and poplar. Black spruce typically grows on north slopes and poorly drained flat areas. Root depths are shallow. Fire scars are common. White spruce averaging 12 to 24 m in height and up to 40 cm in diameter occurs in mixed stands on south-facing slopes and well-drained soils. Aspen and birch average 15 m in height. Undergrowth consists of mosses with grasses in drier sites and with brush on moist slopes. Typical plants are willow, alder, ferns, rose, high and low bush cranberry, raspberry, currant and horsetail.

To provide more specific vegetation information, Vogel and Slaughter (1972) prepared a vegetation map for the Caribou-Poker catchment. Mapping was based on available aerial photography, with limited ground checking. The resulting map (Figure 6) provides reasonably accurate stand boundary delineations, although subsequent field work has revealed some mistakes in species identification from photos--notably in distinguishing black spruce (*Picea marina*) from white spruce (*Picea glacua*) in lower-slope stands, and distinguishing among deciduous species on southerly slopes. Those with distinct ecotones, such as the riparian community, black spruce and birch-aspen (*Betula papyrifera* - *Populus tremuloides*), were identified with a higher degree of reliability. It is no accident that the vegetation map closely resembles the soil map; ecologists and soil mappers recognize the close interrelationships between vegetation and soils, and use this in making their respective analyses. Some communities are less specific to certain soil conditions than others. An example of how communities may succeed one another on a given soil is white spruce following birch-aspen after fire. Were it not for periodic fires, most of the birch-aspen stands in interior Alaska probably would be white spruce (Lutz, 1956).

Plant community distribution in the research watershed is strongly influenced by topographic position and exposure, in accord with expected patterns for interior Alaska (Figure 7). Permafrost-underlain, north-facing and valley sites are occupied by black spruce, limited birch and aspen, alder, sedge, and riparian communities (Figures 8, 9). Warmer well-drained, south-facing slopes, with deeper soils, commonly support thrifty stands of aspen, birch, and white (and sometimes black) spruce. Major alder and willow components often occur (Figure 10). In the Caribou Creek drainage, commercial quality white spruce is largely limited to "stringers" and localized stands at higher elevations. These white spruce are commonly associated with minor topographic depressions, which presumably provide better soil moisture conditions (Quirk and Sykes, 1971). Similar relationships presumably exist in the Poker Creek headwaters where several discrete stands of white spruce occur in P-2 at elevations similar to those in C-2.

Fire has clearly been an active force in the watershed. Charred stumps are found throughout the basin and charcoal is common in the soil profile. Fire scars on existing trees indicate widespread burning in the 1905-1910 era, though it is clear that at least isolated stands (such as mature white spruce stringers) were not decimated in that period.

As would be expected, soil series distribution and plant species distribution are in reasonably good accord. In Caribou-Poker creeks, the Ester soil series is invariably associated with a black spruce community, deep moss cover, and permafrost. Riparian plant communities occupy the alluvial Bradway and Karshner soil series. The permafrost-free Gilmore and Olnes soils support deciduous birch, aspen, willow and alder stands, as well as both black and white spruce. Ground cover under birch-aspen or white spruce is distinctly different than under communities where moss is prevalent with a deep organic layer. White spruce may grow in alluvial bottoms and, under certain circumstances, can induce local ground-ice accumulation (Vierick, 1965). However, no major stands of white spruce growing on alluvium are known in this watershed.

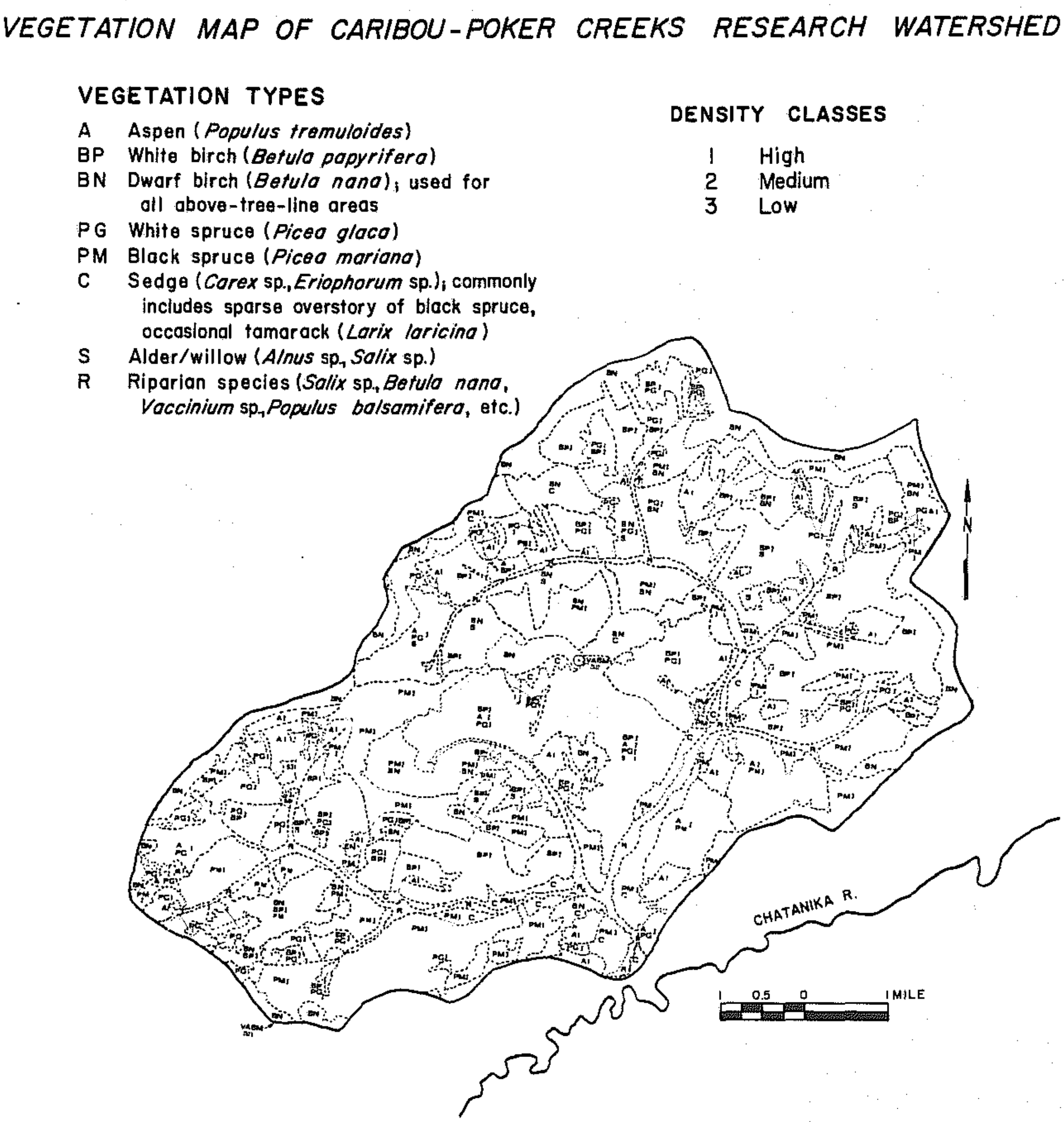

Figure 6. Vegetation map of the watershed (after Vogel and Slaughter, 1972).

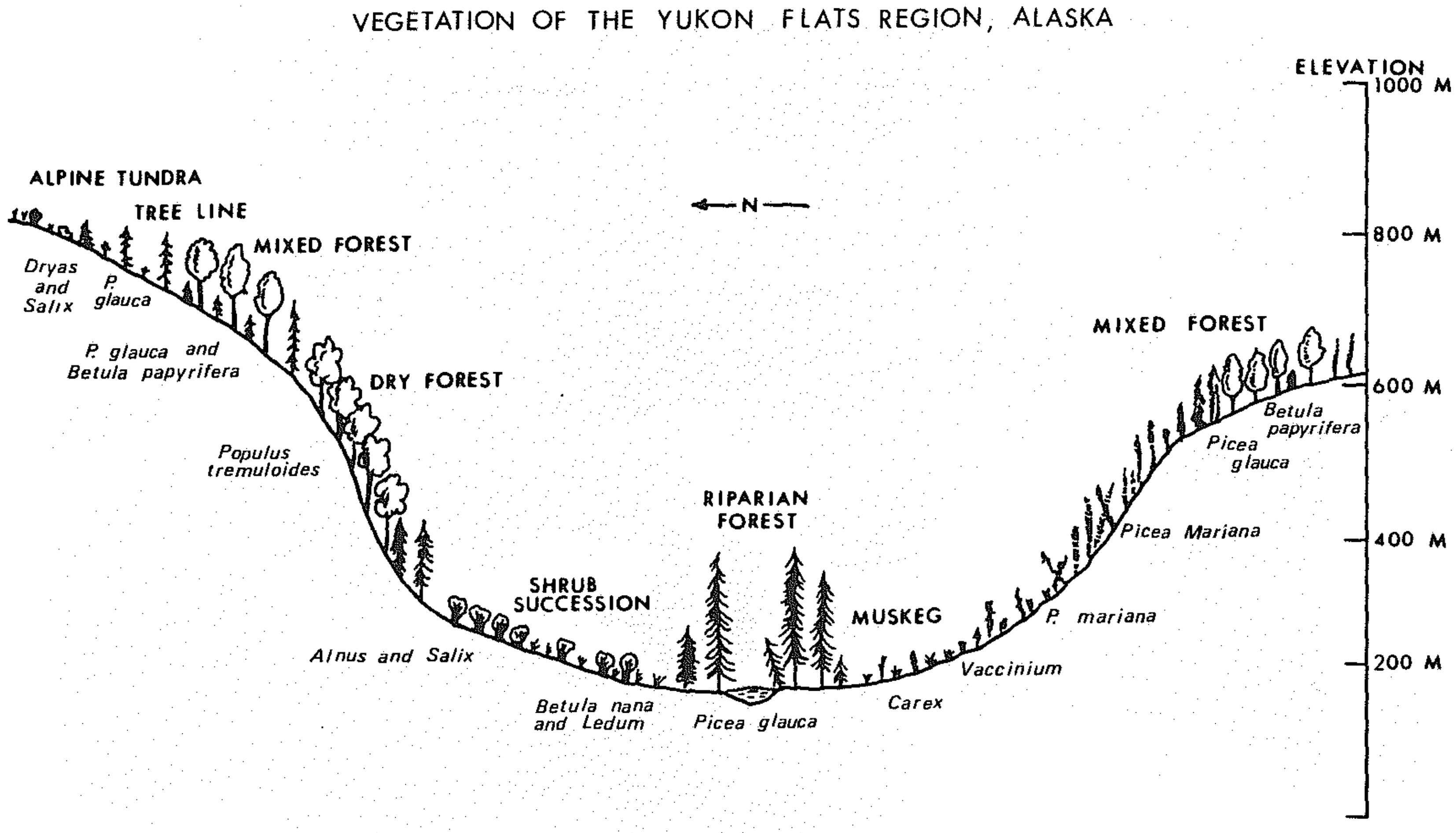

Figure 7. Vegetation types on a north-south valley transect including the influence of elevation (after Johnson and Vogel, 1966).

Figure 8. Appearance in winter of black spruce community on north slopes (left side) contrasted with birch-aspen on south (right), view looking up Caribou basin. Note the sharp ecotone between birch-aspen and valley conifer community. Two pingos are visible.

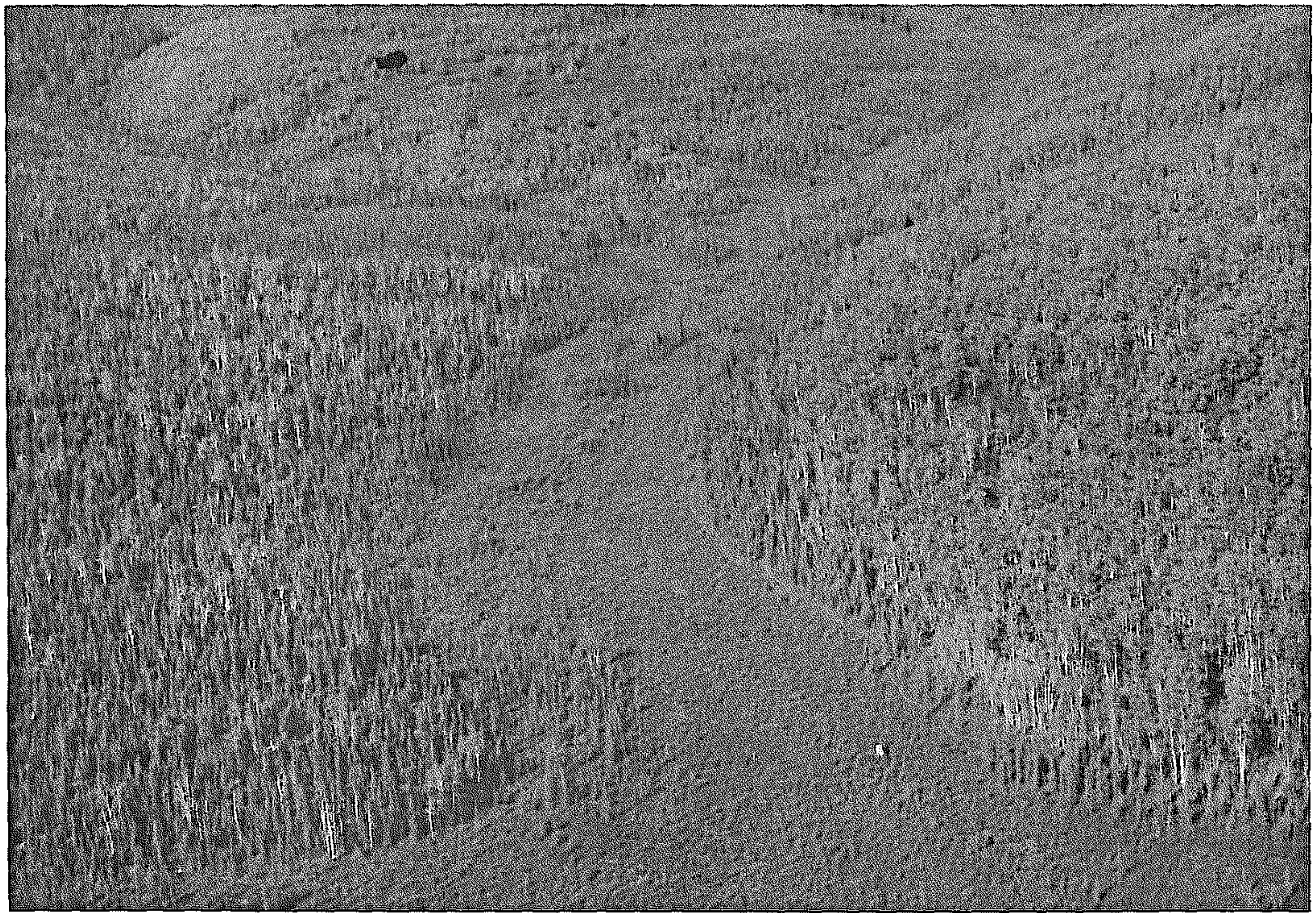

Figure 9. Low-level view showing summer appearance of contrasting vegetation across a north-south valley (C2) looking north. Mixed white spruce and hardwoods at left, valley shrubs in cneter, and birch-aspen on right. Note the narrow fringe of conifers between the valley and the brich-aspen communities. The tributary stream (C2) is completely obscured by riparian vegetation.

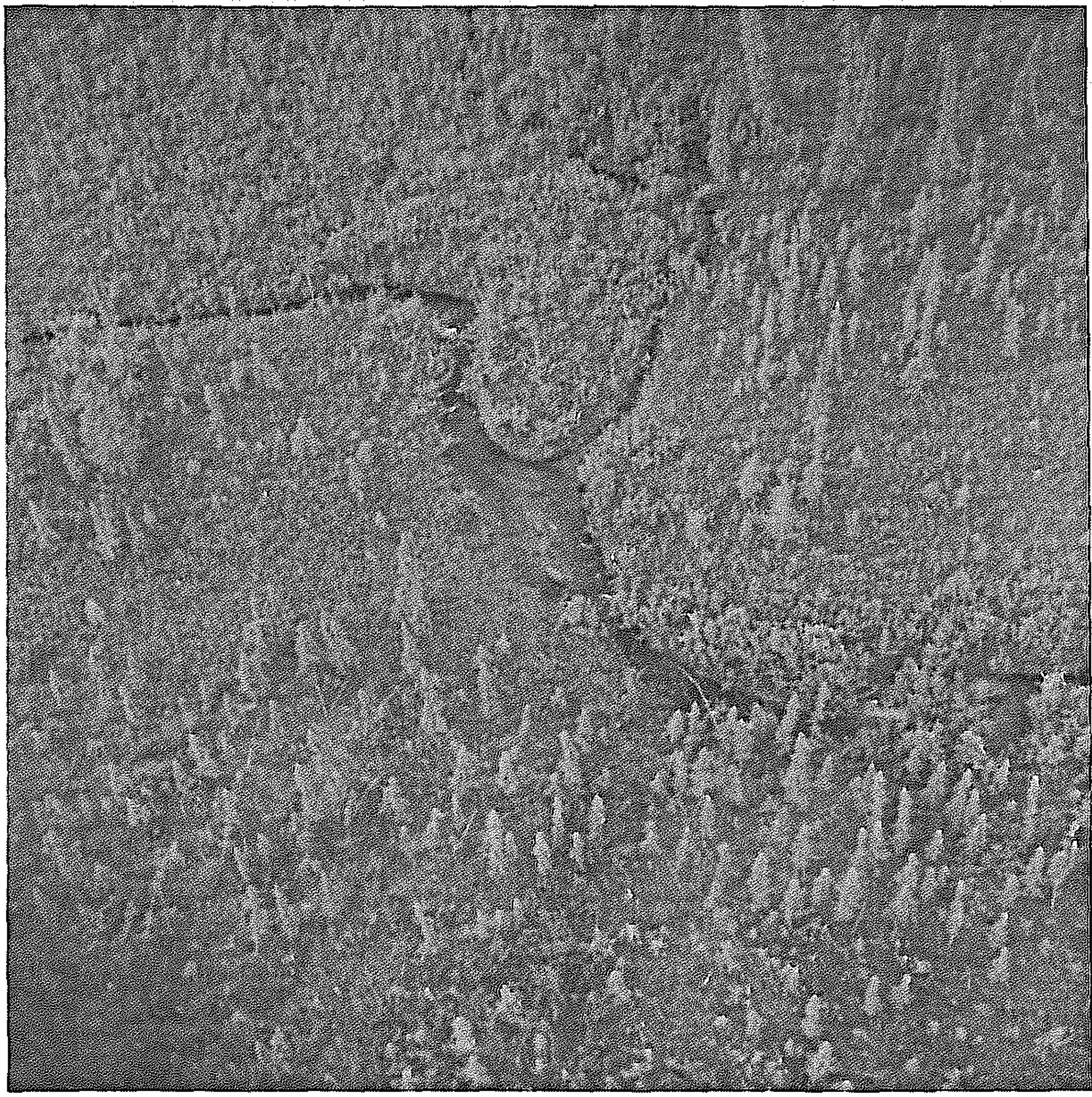

Figure 10. Low-level view of valley vegetation typical of these small basins at the confluence of P1 and P2. Here black spruce is interspersed with the valley shrub community. Flow is from top to bottom right.

Runoff characteristics appear to vary among the vegetation-soil units. The areally abundant Olnes-Gilmore soils and vegetation with a thin organic layer will apparently provide abundant runoff during moderate to heavy rainfall (storm exceeding 1.5 cm precipitation). Soils with deep organic accumulation should retain a much higher proportion of rainfall. All soils tend to yield heavy surface runoff at spring snowmelt because they are frozen, but soils with deep organic layers may retain large amounts of meltwater. Bredthauer and Kane (personal communication), working on apparently similar sites near Fairbanks, have not observed surface runoff even during the height of snowmelt. On the other hand, Aldrich (1979) observed very high rates of surface runoff on one south-facing slope of Poker Creek during spring 1978. Quirk and Sykes (1971) concluded that the runoff pattern for birch-aspen or white spruce slopes resembles that of similar sites in temperate regions, because soils under these communities are only seasonally frozen during the winter and early spring.

SOIL-VEGETATION INTERACTIONS

Troth et al. (1975) conducted an intensive study of species distribution and soil profile characteristics in eight selected plant communities in the Caribou Creek drainage. Of the eight stands studied, three were birch/aspen communities on Olnes or Gilmore soils. The remaining five stands were black spruce. Three occurred on permafrost-underlain Saulich or Ester soils, and the other two developed on soil series transitions (Olnes-Gilmore, Olnes-Fairplay). No stands were selected that represented vegetation growing on what was definitely a Fairplay soil, nor were any stands studied in the Poker Creek drainages.

These workers described the vegetation communities, using sample plots of various sizes to obtain a representative sample of each community (details are not presented here) for each stand. Laboratory analyses of each plant and soil material followed standard procedures recommended by specialists working in the fields of plant and soil chemistry. The intent here is to discuss their data and relate them to overall functioning of the watershed as an ecosystem.

In the soils phase of their study, Troth et al. analyzed forest litter as well as mineral soil. Total dry weight of the organic mat ranged from 120.3 metric tons/hectare under black spruce to 44.8 metric tons/hectare under hardwood. Total weight appears generally to be a function of thickness of the organic layers. Coniferous stands, with a greater thickness of organic layers, show a higher total litter mass than do the hardwood stands. However, on a mass/litter-depth basis, the hardwoods average higher than do the conifers, 5.9 metric tons/cm vs 5.3 metric tons/cm, respectively. This suggests that the hardwoods, with their shorter life, will out-produce the older black spruce communities; this may influence how these contrasting communities are to be managed.

Data on total mass of nutrients/hectare presented by Troth et al. show that hardwoods contain more nutrients than the conifers (2.88 vs. 1.93 metric tons/ha, respectively) even though the organic mat under a coniferous cover is thicker and averages a higher total mass. These data permit several generalizations regarding type of ground cover. Moss plus lichen coverage was 85% under black spruce, compared to 11% under hardwoods. Differences in ground cover influence soil moisture relations, runoff characteristics, and thermal regimen, which are all important elements of watershed hydrology. As hardwood succession proceeds toward an expected climax white spruce stand, coverage of the moss and lichen layer would be expected to increase, but not as much as black spruce communities. Three species of lichen (Cetaria spp. and Cladonia alpestris) were entirely absent from hardwood stands, yet were always present in the conifer stands; the shrub Rosa acicularis was always present in hardwood stands but absent in the conifer stands.

Troth et al. point out that carbon/nitrogen ratios are substantially lower in organic layers under hardwood than under conifers, while the opposite is true with respect to nitrogen content. As they suggest, nitrogen may be immobilized at C/N ratios from 20 to 30, tending to prevent mineralization under these conditions. The pH under hardwoods is considerably higher than under the conifer stands; the upper layer under all stands was less acid than the underlying layer. It appears that as decomposition proceeds in the lower layers, hydrogen ions are released, tending to reduce pH. Although nitrogen concentration in the hardwood litter was nearly double that under conifers, differences between the upper and lower layers were slight and do not appear to show a consistent trend. Chemical composition of the litter also differed, with hardwoods being higher in P, Ca, and Mg content. Potassium appears to be little affected. Iron behaves differently than other elements and reaches maximum levels in the more acidic layer under both hardwood and conifer stands. Total mass of organic layers and chemical composition of the material is concluded to be similar to reported values in similar environments. These data may, therefore, be considered to represent conditions that extend beyond the watersheds being studied.

Large differences in temperature at the root zone under hardwoods versus conifers have been observed (Slaughter and Long, 1974), reflecting the influence of varying solar radiation input to south-facing and north-facing slopes. Previous work in similar environments led Dr. Paul Heilman (personal communication) to conclude that soil temperature in the root zone was the most limiting factor in taiga productivity. Plant nutrients can apparently produce reasonable growth when temperatures and moisture are favorable.

Except for the low pH, nutrient levels are similar to those of many agricultural soils. Although Troth et al. (1975) list sand, silt, and clay contents, no effort was made to evaluate the effects of varying quantities of gravel in these profiles. Since most of the upland soils described by Rieger et al. (1972) showed increased gravel content with depth, some measure of the gravel present in each layer would be helpful for interpreting data such as cation exchange capacity, percent base saturation, and water relations.

Thus the organic forest floor, in terms of total mass and nutrient content, resembles that reported for similar environments and does reasonably represent the taiga. All studies in the Caribou Creek basin should represent similar environmental conditions in the Poker Creek basin; however, examples of the Fairplay soil series and the companion vegetation complex should be similarly studied. Floristic composition of the understory vegetation also changes with the major communities, (black spruce versus hardwoods); ericaceous species are scattered under black spruce compared to the intermittent cover of deciduous shrubs under hardwoods.

WATER QUALITY

Although EPA had collected and analyzed water samples from Caribou-Poker Creeks since 1969, the sampling was neither systematic nor prolonged. However, systematic sampling at monthly intervals was completed in the summers of 1971 and 1972. Eleven sites were sampled over seven sampling periods. The preliminary evaluations of these water quality data are reported in Jinkinson et al. (1973), who concluded that Caribou and Poker creeks are naturally dissimilar--although the differences are not large. A more complete interpretation of the 1971 and 1972 data is found in Lotspeich et al. (1976). Field analyses for conductivity, pH, alkalinity, and dissolved oxygen were made, and samples were collected for laboratory analysis. Field work was continued in 1974-1975 to obtain water quality data during winter. Only the data for 1974 are reported in Lotspeich et al. (1976).

Water quality in streams of this catchment is good to excellent. Turbidity is low, except for moderate increase during breakup. Organic nutrients are near the lower limits of detection. Available nitrogen is primarily the NO_3 ion; there is little variability among streams. The very low levels of ammonia, nitrite, and phosphate are typical of unpolluted streams draining pristine areas. Essential trace metals are low but detectable, suggesting that zinc, copper, and manganese are at levels sufficient to support aquatic life. Lead, arsenic, and mercury are barely detectable. Dissolved base metals are dominantly calcium followed by magnesium. Potassium and sodium are in the 1-2 ppm range. Variability among streams is considerably greater for the bases, calcium and magnesium, than for other essential ions. Conductivity, a collective measure of all ions, shows considerable variability among tributary streams. Poker Creek water, at the confluence with Caribou Creek, is considerably higher in ionic metals than is Caribou Creek. A similar relationship is indicated for total alkalinity, which tends to be higher for Poker Creek than for Caribou Creek waters. Summer water temperatures among tributaries showed moderate variability; Poker Creek was consistently warmer than Caribou Creek when measured near their confluence. No trends were observed for pH, which ranged from 6.6 to less than 8.0. Most values fell between 7.0 and 7.4. Dissolved oxygen was nearly saturated throughout the summer. An inverse relationship exists between conductivity and discharge. Higher conductivity values occur at lower discharges as these streams approach base flow and water is chiefly derived from groundwater.

Prior to 1974, all data were derived from summer sampling, which is less than half of the annual water year in these basins. In the fall of

1974, EPA attempted to correct this deficiency by working at regular intervals throughout an entire winter. The Caribou Creek basin was chosen for study because of ready access to all tributaries. Samples were taken from Poker Creek at the confluence of the two for comparison. Data were acquired in this program through December until deep ice obscured the channels of these small streams. However, sampling continued biweekly for Caribou and Poker creeks and monthly for Caribou Creek (3 km below the confluence of C-1 and C-2), until after breakup in May.

Data from October through December 1974 (Table 2) show that conductivity of both Caribou and Poker creeks tends to rise as ice covers these streams and flow diminished. The conductivity of Poker Creek continues to be somewhat higher, which is similar to summer observations. Conductivities of C-1 and C-2 are very similar and do not rise over the three-month period, but they are higher than summer values. Conductivities of C-3 and C-4 are considerably higher than C-1 and C-2; otherwise, they behave similarly and are probably the dominant ionic source contributing to the Caribou Creek basin. Alkalinity in these streams is higher in winter than in summer, but it does not continue to rise as winter progresses. In fact, December levels were lower than those for October in all streams. Dissolved oxygen decreases somewhat by the end of December, but not to a critical level. The range in pH changes is small and remains at the optimum level for aquatic life.

Table 3 presents laboratory data for the same period as the preceding table for field chemistry. Calcium and sulfate ion patterns parallel those of conductivity when winter data are compared with those of summer. Values for both ions tend to be higher in winter but do not increase appreciably from October through December. Data presented in Lotspeich et al. for C-3 and C-4 show that sulfate of C-3 is about double that of all other tributaries, although not increasing with time. Data from C-3 and C-4 are omitted from Table 3 because this table presents a full winter's data for several streams, and samples of C-3 and C-4 were not collected after December 1974.

During the 1974-1975 winter, conductivity of Poker Creek tended to be higher than that of Caribou Creek, reaching a maximum during the first week in April; Caribou Creek reached its maximum in late February. No explanation is offered for this behavior. Alkalinity in Poker Creek continued to be higher than in Caribou Creek but tended to decline with small fluctuations after reaching a maximum in October and November. Changes in pH were minor for both streams throughout the rest of the winter, pH remaining close to neutral. Dissolved oxygen continued to decline after December in both streams. Caribou Creek reached a low of 2.5 ppm in February under 3 m of ice; the minimum for Poker Creek was 5.3 ppm in March. Even with winter ice, both streams showed an increase in DO after these minima.

Data for C-1 and C-2 (Table 2) are combined from January to April because ice conditions prevented sampling of the individual streams. At one point on the stream where the ice was thin, samples could be collected for cojoined waters of C-1 and C-2. The data for C-1 and C-2 late in the winter are very similar to data from the two individual

TABLE 2. FIELD CHEMICAL DATA, WINTER 1974-75. CARIBOU-POKER CREEK RESEARCH WATERSHED.

	PM				CM				C1				C2				C3				C4			
Date	Cond.	pH	Alk.	DO	Cond.	pH	Alk.	DO	Cond.	pH	Alk.	DO	Cond.	pH	Alk.	DO	Cond.	pH	Alk.	DO	Cond.	pH	Alk.	DO
1974																								
4/12	150	7.4	120	13.7	87	7.2	63	11.3																
6/13	120	7.7	85	12.4	100	7.8	77	12.7																
10/25									66	7.6	52	12.4	85	7.9	60	13.1	125	7.6	71	13.3				
10/30	150	7.2	120	12.6	120	7.2	94	12.6													120	7.4	96	13.3
11/14	155	7.2	119	12.8	125	7.5	96	12.2																
11/22									70	7.1	—	8.2	80	7.0	—	12.1	115	7.0	—	12.6				
11/26	150	7.1	65	12.3	125	7.1	54	12.4													130	7.4	55	12.4
12/10	175	7.0	67	12.2	140	7.1	53	11.0																
12/18									75	6.6	28	6.9	85	7.1	33	10.0	130	6.9	42	9.5	125	7.1	56	12.1
12/24	170	7.0	68	12.2	140	7.2	56	10.6																
1975									CL + C2															
1/23	205	7.3	86	7.4	190	7.2	78	9.5																
1/24									70	7.1	39	11.0												
2/6	175	6.8	70	7.4	160	7.0	62	8.5																
2/21	215	7.0	91	5.9	220	6.8	94	2.5	97	7.2	40	10.3												
3/6	205	6.9	86	5.3	170	6.9	64	7.8																
3/20	220	7.0	90	5.9	160	7.1	64	10.0	95	7.0	37	10.9												
4/3	240	7.0	90	8.4	165	7.0	68	8.9																
4/17	190	7.1	75	11.2	150	7.0	63	9.1	90	6.9	37	11.4												
1975									C1				C2											
5/28	101	—	33	12.4	48	—	26	11.6	66	7.3	15	11.7	26	7.7	22	11.8					76	7.3	30	11.7

streams earlier in the winter. The combined data approximately match observations made on the individual streams. Both C-1 and C-2 are lower in conductivity and alkalinity than are the other four streams sampled in winter; pH is about the same for all. Dissolved oxygen remained at about 10 mg/l in C-1 and C-2, probably because of unobserved breaks in the ice cover which permitted aeration. Samples collected on 28 May 1975 (after breakup) show a dramatic decrease in conductivity and alkalinity for all streams compared to the previous month. Dissolved oxygen was then near saturation in all streams.

Table 3 presents data from laboratory analyses of samples collected during winter months. These data confirm results of similar analyses for samples collected in the first half of the 1974-1975 winter season. Calcium is the dominant cation, followed by magnesium; sulfate is the dominant anion. Total hardness, an approximate measure of calcium plus magnesium, appears to be much higher in winter than in summer, as indicated by comparing prebreakup and postbreakup data (April 1974 and 1975 vs. June 1974 and 1975). Although levels of hardness fluctuate, they remain high throughout winter. C-1 and C-2 are relatively low in ionic strength as shown by results for sulfate, calcium, magnesium, potassium, and sodium. This confirms the field measurements of conductivity, which were low in these basins compared to C-3 and C-4. Data from the second half of winter for C-1 and C-2 show that these trends continue through the remainder of the winter. Unfortunately, similar data for C-3 and C-4 are not available. The range of total hardness for C-1 and C-2 was about half that for the entire Caribou basin (CM), thus confirming the results for individual ions.

In the spring of 1975, a trail was opened from the confluence of Caribou and Poker creeks, up the Poker Creek valley to P-1 and P-2. This permits foot or tracked-vehicle access to all subdrainages in the Poker Creek watershed. Consequently, EPA conducted a sampling program in Poker Creek during the winter of 1975-1976, similar to that completed for Caribou Creek the previous winter. Chemical data acquired in this effort are listed in Tables 4 and 5.

Because it was very difficult to find water in very narrow channels under the thick ice of Caribou Creek, all Poker Creek sites selected for sampling were marked before ice covered the streams. Pools that appeared permanent were marked by tying bright flags to bushes on opposite banks of the pool. In addition, two 2-m long, 1-cm diameter bars, spaced about 0.7 m apart, were driven into the bottom of each selected pool to mark the position for subsequent drilling by ice auger. As installed, these bars projected about 1.2 m above the open water level to allow relocation of the pool when ice was less than 1.2 m thick. The idea was sound but it was later found that extensions should have been added to give at least a total of 2.5 m height above summer water levels at some sites. At sites such as P-1 and P-2, where stream gradients are steep, 2 m of rod above the water level is probably sufficient; but where gradients are moderate to low, longer markers are necessary. Another problem arose when sampling was attempted in December 1975 at P-4. Although the marking rods were visible, no water was encountered when a hole was drilled through about 1.2 m of ice. Evidently, these

TABLE 3. LABORATORY ANALYSIS OF CARIBOU-POKER CREEKS, WINTER OF 1974-1975.

Sta	Date	SO_4	SiO	Ca	Mg	K	Na	Fe	Cl	TH[1]	
CM	04/12/74	7.5	8.8	13.4	3.3	1.0	1.5	1.16	—	143	
"	06/13/74	4.5	8.9	14.1	2.6	0.9	1.3	0.13	—	44	
"	10/30/74	9.5	8.0	17.1	3.3	0.7	2.1	0.12	0.8	30	
"	11/14/74	8.6	8.0	17.8	4.1	0.9	2.2	0.15	0.4	54	WP#30
"	11/26/74	9.0	8.0	18.3	4.0	0.7	2.2	0.34	0.5	62	
"	12/10/74	8.9	8.0	18.5	4.3	0.8	1.8	0.43	0.5	62	
"	12/24/74	8.7	7.8	19.2	4.3	1.0	1.9	0.40	0.5	66	
"	01/23/75	15.5	12	—	—	2.1	3.8	0.11	1.9	105	
"	02/06/75	13.0	14	—	—	1.7	2.6	0.16	—	91	
"	02/21/75	20.5	17	—	—	2.3	3.6	0.04	1.3	118	
"	03/06/75	15.0	13	—	—	1.8	2.6	0.68	0.9	89	
"	03/20/75	10.5	—	—	—	1.5	2.2	0.12	—	73	
"	04/03/75	10.0	11	—	—	1.4	2.2	—	2.1	74	
"	04/17/75	9.0	10	—	—	1.3	2.0	0.04	0.5	86	
PM	04/12/74	14.4	8.0	22.0	4.0	1.3	1.7	0.19	—	295	
"	06/13/74	9.0	6.1	16.3	2.9	1.0	1.3	0.42	—	46	
"	10/30/74	10.8	7.5	23.6	4.1	0.8	2.2	0.24	1.4	51	
"	11/14/74	11.5	7.0	23.3	4.9	0.9	2.1	0.08	5.7	84	WP#30
"	11/26/74	11.2	7.5	22.6	4.9	0.8	2.1	0.08	1.1	73	
"	12/10/74	11.1	7.2	23.8	5.1	0.9	1.7	0.14	1.9	79	
"	12/24/74	10.9	7.2	23.5	5.0	1.0	1.8	0.16	0.9	75	
"	01/23/75	15.5	11	—	—	1.9	2.8	0.20	—	104	
"	02/06/75	34.0	14	—	—	2.1	3.0	0.18	—	84	
"	02/21/74	17.5	11	—	—	1.4	2.4	0.16	2.5	65	
"	03/06/75	18.5	11	—	—	1.4	2.8	0.08	0.8	92	
"	03/20/75	19.5	—	—	—	1.8	2.8	0.08	0.9	99	
"	04/03/75	20.0	13	—	—	1.8	2.8	—	1.4	121	
"	04/17/75	16.5	10	—	—	1.5	2.0	0.04	0.6	88	
C1	10/25/74	4.3	8.0	9.0	1.9	0.4	1.4	0.19	1.8	41	
"	11/22/74	5.6	7.5	9.4	2.6	0.4	1.5	0.26	0.7	36	
"	12/18/74	4.9	7.3	9.7	2.7	0.4	1.3	0.56	0.6	32	WP#30
C2	10/25/74	6.6	8.0	10.7	3.3	0.5	1.3	0.08	1.1	46	
"	11/25/75	7.4	7.5	10.0	4.0	0.4	1.4	0.16	0.4	44	
"	12/18/74	6.6	7.2	10.0	4.0	0.4	1.1	0.11	0.3	40	
C1+C2	01/23/75	5.0	10	—	—	0.7	1.6	0.16	—	51	
"	02/21/75	3.0	10	—	—	0.7	1.5	0.04	0.6	48	
"	03/20/75	4.0	10	—	—	0.7	1.5	0.04	0.8	55	
"	04/17/75	3.5	10	—	—	0.8	1.4	0.12	0.4	38	

[1] Total hardness.

TABLE 4. FIELD CHEMICAL DATA, POKER CREEK, WINTER 1975-76.

DATE	P1				P2				P4				P6			
	Cond.	pH	Alk.	DO	Cond.	PH	Alk.	DO	Cond.	pH	Alk.	DO	Cond.	pH	Alk.	DO
11/04/75	165	7.5	67	12.5	125	7.4	59	12.8	95	7.2	43	11.0	180	7.3	64	10.5
12/17/75	150	7.4	60	11.6	125	7.4	47	10.5	No water				190	7.3	84	6.8
01/20/76	150	7.5	61	12.2	120	7.7	47	10.0	Ice fills former channel							
04/09/76	160	7.2	62	13.0	125	7.2	50	10.2								

TABLE 5. LABORATORY ANALYTICAL DATA, POKER CREEK, WINTER 1975-76.

Sta	Date	SO_4	SiO_2	Ca	Mg	K	Na	Fe	NO_3N	Cl	[1]TC	[2]TH
P1	11/04/75	15.4	12.7	21.7	5.6	1.06	1.20	0.18	0.18	3.00	3.5	92
"	12/17/75	14.0	13.4	19.4	4.6	1.12	1.24	0.33	0.11	0.45	2.8	67
"	01/20/76	15.4	11.4	20.4	4.9	1.20	1.23	0.13	0.16	0.64	4.9	75
"	04/09/76	—	1.1	2.2	5.4	1.12	1.22	0.77	0.17	—	—	28
P2	11/04/75	13.6	12.4	14.1	5.3	0.73	1.11	0.32	0.39	0.48	5.2	69
"	12/17/75	15.0	12.8	17.5	4.7	0.85	1.14	0.30	0.25	0.48	7.7	62
"	01/20/76	13.4	10.4	14.0	4.8	0.82	1.16	0.20	0.35	1.40	4.2	60
"	04/09/76	—	0.9	14.9	4.8	0.74	1.13	0.06	0.29	—	—	80
P4	11/04/75	6.6	11.6	11.9	2.6	0.83	1.25	0.32	0.03	0.87	7.0	50
P6	11/04/75	17.2	13.3	21.1	4.5	1.13	1.74	0.33	0.09	4.80	5.6	139
"	12/07/75	15.4	12.9	26.8	5.2	1.35	1.78	0.39	0.06	3.00	4.9	54

[1] Total carbon.

[2] Total hardness.

small channels may intermittently freeze to the bottom. Flowing water must either be diverted upstream to form aufeis icing (common in these watersheds) or rerouted through alternative channels on subchannel gravels. No channel was visible at P-4 or P-6 after December because the ice was too thick. The rods at P-1 and P-2 served their purpose, even though covered with several centimeters of ice, and samples were obtained 9 April 1976, about a month before breakup.

Conductivity in the Poker Creek tributaries (P-1, P-2, P-4, P-6) was higher during the 1975-76 winter than in the 1971-1972 winter, but not as high as for the winter from Poker Creek. A similar relationship existed in 1974-75 for Caribou Creek, when the mainstream (at the confluence) had a higher conductivity than any tributary. P-1 and P-6 had the highest conductivity of these four streams. (Summer data show the same relationship: P-1 and P-6 were highest in conductivity, though not as high as in winter.) Conductivity did not rise appreciably after November 1975. Alkalinity shows less variability than conductivity, but it does rise somewhat during winter; this was suggested by the data for Poker Creek from the previous winter. Dissolved oxygen remained at a moderate level through the winter in P-1 and P-2; no late-winter data are available for the other two streams, although P-6 was down to 6.8 mg/l in December. All streams have a pH ranging from 7.7 to 7.2, which is well within the optimum level for aquatic life.

Laboratory data for the same period indicate that Poker Creek tributaries are higher in sulfate than are Caribou Creek tributaries, and that sulfate is generally higher in winter than in summer. Sulfate was highest in P-6, although only two winter sampling dates are represented; P-6 data from summer samples were also consistently higher in sulfate than other tributaries of Poker Creek. In fact, P-6 was higher than all streams sampled in the summers of 1971-1972. Poker Creek tributaries tended to be higher in calcium than were tributaries of Caribou Creek. Calcium contents tended to rise in winter, compared to summer, but the rise did not continue as winter progressed. P-6 was highest in calcium (26.8 mg/l in December) of all streams sampled. Magnesium levels tended to rise in winter, and Poker Creek tributaries were higher in this base than those of Caribou Creek. The one exception is P-4, which is low in magnesium both summers and winters compared to all streams in the entire watershed; calcium and sulfate were also low in P-4 waters as compared with all other tributaries. Thus, there are two adjacent basins, P-4 and P-6, one of which (P-6) appeared to be highest of all streams in calcium, magnesium and sulfate, while the adjacent basin (P-4) was lowest of all these ions. Other parameters listed in Table 5 did not show significant summer to winter variability, although chloride in P-6 was high; this may be related to the higher levels of sulfate, calcium, and magnesium. All these waters are the bicarbonate type with a pH less than 8 and are moderately well buffered, as shown by their alkalinity. Cationic content is dominantly calcium followed by magnesium; the dominant anion is sulfate with minor amounts of chloride.

The main objective of this sampling program was to obtain a reliable estimate of selected chemical characteristics, and to assess variability of these parameters among the various tributaries. Several generalizations are warranted; however, these in no way imply conclusive results. The data reported here are believed to represent the true status of these waters at the time of sampling; field sampling was properly executed and analytical results are reliable.

It can be stated categorically that none of these streams were polluted, as evidenced by ion contents of phosphate, ammonia, or other nitrogenous substances. Heavy metals were low, indicating little or no mineralization even though near an area (Chatanika Valley) known to be well mineralized. All basins were similar with respect to their hydrochemistry, but enough variability existed among the eight subbasins to permit grouping of them based on hydrochemistry. The chemistry of Caribou Creek versus Poker Creek showed enough persistent differences, at all seasons, to conclude that they drain basins with slightly different geochemistries.

One research objective when setting up the watershed was to program selected disturbances in a basin and monitor the effects of such disturbances on water quality. If comparisons of pretreatment and posttreatment conditions are to be valid, previous knowledge of water quality must be available before disturbance and the natural variability among basins must be assessed. Data reported here show significant variability among basins, but data are inadequate to thoroughly characterize each basin with respect to long-term variability at all seasons. Several years (at least 5) of systematic sampling should be completed before a planned disturbance is applied to an individual basin.

Hem (1959) gives a thorough treatment of water quality sampling, significance of analytical results, and interpretation of the data; this paper is recommended reading for anyone planning a water quality study.

AQUATIC BIOLOGY*

Closely related to physical and chemical water quality as a net indicator of watershed functioning is aquatic life, which reflects an integrated response to water quality. Aquatic communities respond to, and have evolved in response to, the physical environment in which they live; aquatic communities are sensitive to subtle, though perhaps long-lasting, changes as well as drastic modifications of habitats. A proper understanding of these communities and how they function can provide watershed scientists with an early indicator of how watershed management may change water quality. A qualified aquatic biologist, by assessing changes in these communities as they respond to subtle changes in their environment, can detect possibly deleterious effects of pollutant substances before they become evident through chemical or physical analyses. A healthy, diverse, and stable benthic community is a reliable indicator of high-quality water and should be given equal attention with other aspects in the total ecological assessment of a watershed. Historically, this has not been the usual case but the benthos is fast becoming recognized as an essential ingredient in watershed research (Lotspeich, 1978).

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*The initial benthic sampling and analysis were conducted by E. Schallock and William Jinkinson at EPA's Arctic Environmental Research Station. This section is based on their preliminary work.

Benthic samples were first collected in the Caribou-Poker creeks drainage in 1969, when sites at C-2, C-3, and CM (USGS gaging station) were sampled on October 20. Additional sampling of C-3 and P-1, P-2, and P-6 occurred in July 1970, but not as part of a systematic program. In 1971, all streams in the research watershed were sampled for qualitative presence of benthic life near the mouths of each drainage unit (11 stations in all). This program was part of the broader water quality sampling referred to earlier. All samples were obtained in two days with helicopters; this minimized problems of emergence and phenological aspects of life cycles. The first summer's sampling was completed on September 28 and 29, when all stations except C-P were sampled. This program was repeated in 1972; all stations were sampled on May 31 and June 1, and again on August 21 and 22. Thus, although done in two successive summers, benthic samples were obtained each month of the short June-through-September summer. This provides a representative sample of existing benthic communities in the Caribou-Poker creeks basin.

Because of geomorphologic controls over stream morphology, headwater streams (first and second order) have different habitats for benthic organisms than do the higher order streams; low orders merge forming higher orders, finally reaching their base level at a master stream. In the Caribou-Poker basin, all tributaries sampled (8) are first or second order; Caribou mainstream is second order, Poker Creek third, and C-P (below the confluence of Caribou and Poker creeks) is a fourth order stream. All first and second order streams are characterized by steep gradients, with a much coarser substrate than is found lower in the basin. Thus, the stream habitat for first and second order streams may be substantially different than for a third order reach and certainly different from the fourth order reach. In response to this variability in habitat, a parallel variability in composition and ecological requirements of the benthic communities could be expected.

Another factor influencing community composition at various stream orders is food availability and the corresponding ability of organisms to gather and process food. In low order streams (first, second, and third order) most food for aquatic life is of terrestrial origin, from overhanging vegetation debris and transport from adjacent land. As stream order increases, the proportion of terrestrially derived food decreases while primary production in a stream increases. The physical requirements for food processing are thus quite different for organisms of low order streams, compared with higher orders; this should result in different assemblages of organisms. By this reasoning, one would expect a somewhat different community of benthic life in P-1, P-2, C-1, and C-2 compared to that at the Caribou-Poker creeks confluence and below. C-3, C-4, P-4, and P-6, although low order streams, might be intermediate because their base level with the parent stream is at a lower elevation than more headward tributaries. Previous work dealing with benthic communities in Alaska has been chiefly concerned with fifth order (or higher) streams. The Caribou-Poker Creeks Research Watershed is the first basin in interior Alaska for which the benthic communities have been systematically sampled and analyzed, with the objective of describing them in relationship to the habitats of low order streams.

The analysis of Jinkinson et al. (1973) was a first attempt to interpret the material collected during the summer of 1971-1972, and primarily stressed the macroinvertebrates because of their wide diversity and their recognized role in the aquatic foodweb. Although some quantitative samples were obtained, that analysis was based on qualitative samples solely concerned with the taxonomy of the various groups as an initial effort.

Of the 34 taxa recognized, 28 were included in the Class Insecta and will form the base for the following discussion. Within the insect groups, 25 occur within four orders that pass their immature stages in water (two-winged flies, mayflies, stoneflies, and caddisflies). Samples of every station were examined by Jinkinson et al. (1973) who found that numbers of taxa per station ranged from 15 to 24, with most near 20; however, he did not indicate the date of sampling or a habitat type for each sample. Those taxa common to each of the 11 sampling sites included freshwater annelids and representatives of the four major insect orders previously noted. In comparing the Caribou Creek basin to the Poker Creek basin, it was noted that 27 of the 34 taxa are held in common and that four are unique to Poker Creek basin, whereas three are unique to the Caribou Creek basin. Those unique to Poker Creek included a genus of mayflies and two genera of caddisflies; those unique to Caribou Creek are three families of two-winged flies. Again, there was no identification of the sites in which these unique taxa were found; however, it was pointed out that the unique taxa in each basin came from only one or two stations. Moreover, it was speculated that these subtle differences might be caused by small subtle differences in habitat such as substrate, water chemistry, velocity, etc.

Time constraints have precluded a more complete analysis of the material collected during 1971-1972. A logical step will be to process all samples on hand. Both quantitative and qualitative samples are available for analysis; much valuable information is to be gained on diversity, composition, and life cycles of aquatic life in these low order streams when the available material is thoroughly processed. The limited analysis discussed above demonstrated overall similarities among basins with subtle differences, which should not be surprising, but no attempt was made to compare these communities with those of fifth and sixth order streams. Taxonomic analyses are one important first step in assessing watershed aquatic life but, until such analyses are eventually related to the ecological requirements of each community, these analyses will be of limited value in environmental assessment.

CLIMATOLOGY

Climatology of a watershed is probably the most important influence on its total functioning. Two weather elements of climatology (temperature and precipitation) dominate all others. Therefore, extensive effort must be made to obtain a data base for understanding the hydrology of a watershed. Other elements (such as humidity, wind, insolation, barometric pressure, and cloudiness) are of less importance, but a description of the climate of a given basin is incomplete unless temperature and precipitation are included. Daily and seasonal variability of each element must be described since this variability is frequently the factor limiting understanding of the hydrologic functioning of a watershed. Because variability can only be determined when continuous records are obtained, every effort should be exerted to obtain records of key elements.

Fairbanks, with several decades of continuous records, is the nearest first order weather station to the watershed and is generally taken to represent the weather of interior Alaska. One objective of this section is to compare weather data of the watershed with those of Fairbanks to possibly prevent duplication of effort if some of Fairbanks data can be applied to Caribou-Poker Creeks Research Watershed. Hartman and Johnson (1978) consider Fairbanks as having a continental climate characterized by great diurnal and annual temperature variations, low precipitation, low cloudiness and humidity, and with mean annual temperatures of 9.4°C to -3.9°C. Fairbanks meets these requirements with the exception of cloudiness which is moderate to high on an average. Although no mention is made of winds, Fairbanks enjoys a large percentage of days with calm to moderate winds, resulting in severe temperature inversions at all seasons.

One of the first efforts in the research watershed was to establish a climatological network in the Caribou Creek basin, the 41 km^2 catchment designated as "representative" (Slaughter, 1971). A major objective of this network is to assess the orographic effect of certain weather elements such as temperature and precipitation in these small basins and compare them with Fairbanks data. Plans call for expanding the climatological network to the Poker Creek basin, which is designated as "experimental" (Slaughter, 1971). The initial net, established in 1969, consisted of recording thermographs and precipitation gages at Caribou Creek mainstream, basins C-1, C-2, and C-3 near their mouths (elevation 305 m), in C-2 (on a south-facing slope) at 488 m elevation and in C-3, at a similar elevation but on a north-facing slope. Anemometers were established on Haystack Mountain, Caribou Peak, and at the valley station on Caribou Creek mainstream (all instrument sites are shown in Figure 11). It is planned to expand the climatological network into the Poker Creek basin as instruments and personnel to service them become available.

Precipitation

Precipitation is the driving force for streamflow, and provides the primary medium for down slope and down valley movement of earth materials and nutrients. It is unfortunate that data concerning precipitation in the research watershed are scanty and lack continuity. Precipitation has been measured more or less regularly at a number of points concentrated in the Caribou Creek basin.

Air temperature, water temperature, ground temperature and wind data for selected sites in the research watershed have been tabulated in a series of data reports: Slaughter, 1970a,b; Hobgood and Slaughter, 1974; Slaughter et al., 1975; Bredthauer, 1977; Slaughter and Bredthauer, 1977. Unfortunately, precipitation data, with the exception of winter snowfall, have not been similarly tabulated and distributed.

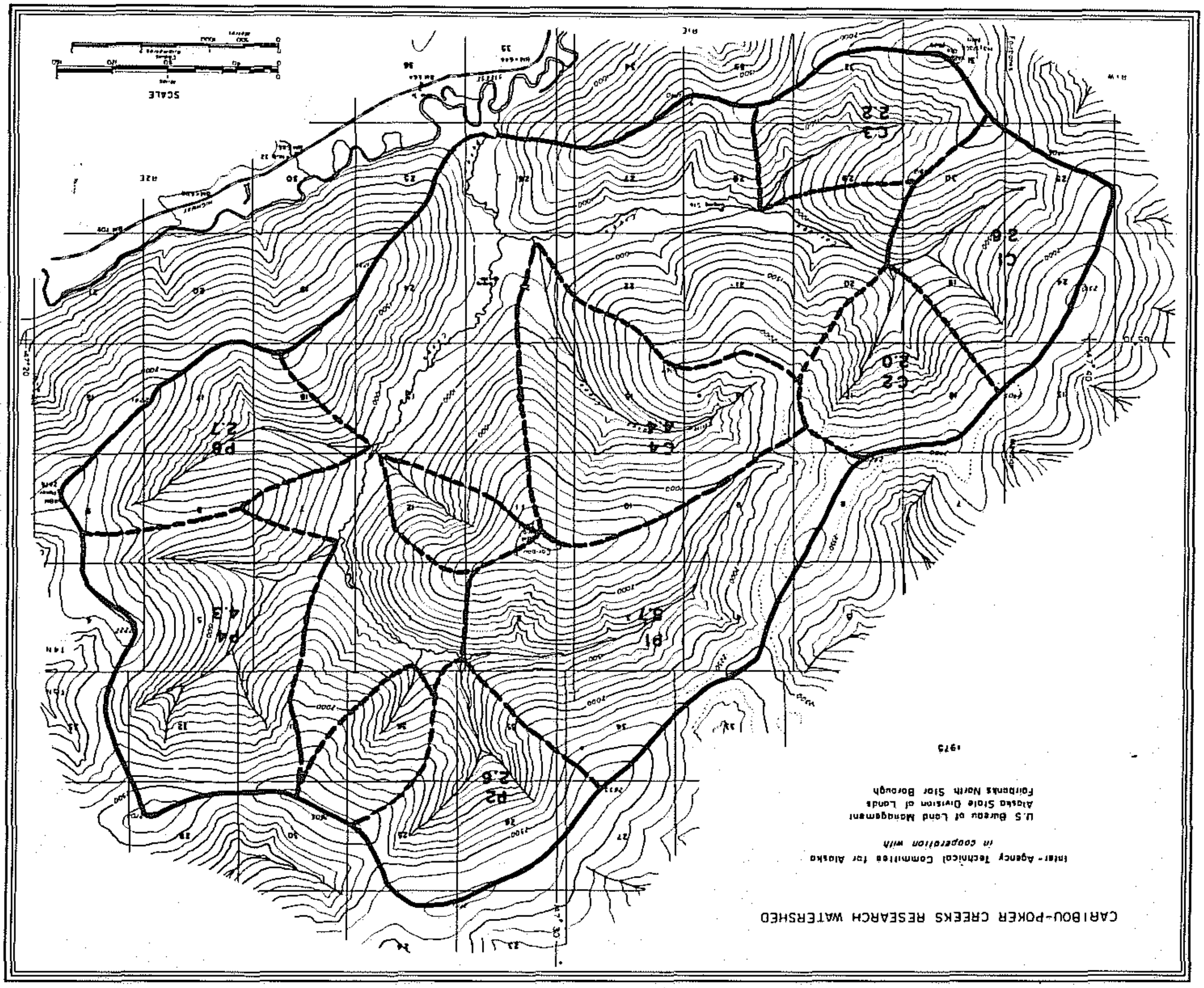

Figure 11. Topographic map of the watershed showing primary drainages (e.g. C4 is drainage number 4 of Caribou Creek, P1 is drainage 1 of Poker Creek) and drainage area in square miles (P1 is 5.7 square miles).

During winter months the primary measurement is at three "snow courses," established lines at which snow depth and water content are measured monthly. Data from the three snow courses in the research watershed are summarized in Table 6; snow course locations are indicated in Figure 11. Maximum snowpack water equivalents were measured during the winter 1970-1971 and 1971-1972; nearly 35 cm water equivalent was observed at the Haystack Mountain course (elevation 594 m) in spring 1971.

A consistent elevational relationship is evident in observed snow data. The highest snow course, Haystack Mountain (elevation 640 m), commonly has up to 50% greater water equivalent on a given measurement date then do either the Caribou Creek (480 m elevation) or the Snow Pillow (380 m elevation) snow courses. Somewhat less marked but still generally consistent is a greater water equivalent, on a given measurement date, at the Caribou Creek course than at the Snow Pillow course.

Summer precipitation has been measured at a greater number of locations in the research basin (Figure 11); several tabulations are available. Precipitation from ten gages for the 1970 summer is summarized in Table 7. Ford (1973) averaged 1970 and 1971 summer precipitation for Caribou Creek (using Thiessen polygons) and compared that with recorded precipitation at Fairbanks (Table 8); consistently greater precipitation was recorded in Caribou Creek.

Lotspeich et al. (1976) established and operated a precipitation gage at the confluence of Caribou and Poker creeks in 1973 (Table 9).

Precipitation data in the files at the Institute of Northern Forestry (INF) include both unreduced charts and preliminary data tabulations. From the latter, summaries have been extracted from the 2,100 ft location of subdrainage C-3 for summer 1974 (Table 10) and for the Caribou Creek valley (at the stream gaging site) for 28 June 1973 through 6 March 1974 (Table 11).

Rainfall records in the Caribou Creek basin for the summers of 1969 and 1970, when compared with Fairbanks data, clearly indicate that summer precipitation in these basins is about twice that of Fairbanks (Table 12). The long-term precipitation records for Fairbanks give a yearly average of nearly 30.5 cm; about half of this is snow. Data in Table 12 show considerable variability among basins and with elevation, but are always greater that that for Fairbanks. Santeford (1976), in an analysis of data from the upper Chena basin, concludes that stations in these small valleys receive about 50.8 cm of precipitation on a yearly average. Santeford's data agree well with data in Table 12 and may be attributed to orographic effects. Convection storm events may be more effective over the uplands in triggering precipitation in summer, thereby causing greater summer precipitation in these highlands than in Fairbanks.

TABLE 6. SNOW SURVEY DATA, CARIBOU-POKER CREEKS RESEARCH WATERSHED[1].

Date	Caribou Creek (439 m)		(Poker Creek) Snow Pillow (312 m)		Haystack Mountain (594 m)	
	Depth[2] (cm)	Water Equivalent[2] (cm)	Depth (cm)	Water Equivalent (cm)	Depth (cm)	Water Equivalent (cm)
2-4-69	28.0	3.3	25.4	2.8	30.5	4.6
3-2-69	3.5	4.8				
3-4-69			28.0	4.0	35.6	5.3
12-3-69	22.0	3.0	20.3	2.8	25.4	3.3
2-4-70	28.0	1.3	25.4	2.8	30.5	4.6
3-2-70	30.5	4.8				
3-4-70			28.0	4.0	35.6	5.3
4-1-70	28.0	3.8	22.9	3.0	45.7	7.6
5-6-70	0	0	0	0	28.0	7.9
2-4-71	96.5	21.6	88.9	19.8	119.4	31.0
3-31-71	101.6	25.1	99.1	24.4	127.0	35.1
5-5-71	43.2	13.7	45.7	15.0	101.6	23.6
2-4-72	78.7	15.2			109.2	23.4
3-2-72	96.5	16.0	86.4	10.3	116.8	25.6
4-4-72	88.9	19.6	78.7	20.8	116.8	22.9
4-29-72	81.3	20.3	73.7	18.3	114.3	29.7
12-5-72	25.4	4.8	25.4	5.3	50.8	11.7
1-30-73	55.9	10.4	50.8	11.2		
2-2-73					83.8	20.3
2-28-73	55.9	12.7	50.8	11.2	78.7	18.0
3-29-73	53.3	12.7	50.8	10.4	83.8	17.8
5-2-73			5.1	1.8	61.0	23.6
12-27-73	5.6	6.1	33.0	5.3	48.3	8.9
2-5-74			40.6	6.6	61.0	10.7
3-1-74	53.3	7.9	48.3	7.6	66.0	12.2
3-26-74	50.8	9.4	48.3	8.1	68.6	13.7
5-2-74	0	0	0	0	61.0	12.7
12-3-74	40.6	7.1	40.6	6.9	50.8	9.9
1-31-75	63.5	10.7	61.0	9.1		
2-4-75					76.2	13.7
2-28-75	58.4	12.4	55.9	10.2	71.1	14.2
3-30-75	61.0	11.4	58.4	11.7	81.3	14.5
5-2-75	30.5	9.4	30.5	8.9(EST)	71.1	19.0(EST)
2-2-76	55.9	8.6	53.3	8.1		
2-3-76					68.6	11.9
3-2-76	55.9	11.2	50.8	9.1	71.1	14.5
4-1-76	68.6	12.7	61.0	10.0	81.3	14.5
4-29-76	0	0			45.7	9.1
4-29-76			0	0		

[1] Data extracted from published Snow Survey Bulletins, issued monthly by Soil Conservation Service, USDA, Anchorage, Alaska.
[2] Each value listed in the average of five sample points at the snow course.

TABLE 7. PRECIPITATION, SUMMER, 1970 (SLAUGHTER, 1972).

	Caribou Creek, Main site, 274 m elevation 8-in weighing raingage		Caribou Creek, Main site, 274 m elevation 8-in nonrecording raingage		Subdrainage, C-3 640 m elevation 8-in weighing raingage		Subdrainage, C-3 640 m elevation 8-in nonrecording storage gage		Subdrainage, C-2 640 m elevation 8-in weighing raingage	
	Precipitation cm of water		Precipitation cm of water		Precipitation cm of water		Precipitation cm of water		Precipitation cm of water	
	Increment	Cumulative	Increment	Cumulative	Increment	Cumulative	Increment	Cumulative	Increment	Cumulative
20-27 May 1970			1.14				1.90			
27 May - 3 June			1.24	2.39			1.65	3.56		
3 June - 10 June	0.25[1]									
10 June - 17 June	1.52	1.78	3.20				4.32			
17 June - 24 June	missing			5.59	2.16[4]			7.87		
24 June - 1 July	missing				3.18	5.33	3.56	11.43		
1 July - 8 July	1.96[2]	1.96			2.84[5]	8.18[5]				
8 July - 15 July	1.17	3.12	8.64		1.52[5]	9.70	4.44	15.88		
15 July - 22 July	1.78	4.90		14.20	1.90	11.61	1.65	17.53		
22 July - 29 July	0.13	5.03	0.13	14.35	0.10	11.71	0.00	17.53		
29 July - 5 Aug.	3.05	8.08	3.05	17.40	3.05	14.76	2.79	20.32		
5 Aug. - 12 Aug.	2.16	10.24	2.34	19.74	2.21	16.97	2.29	22.61	2.79[8]	
12 Aug. - 19 Aug.	0.41	10.64	0.00	19.74	0.51	17.48	0.25	22.86	0.51	3.30
19 Aug. - 26 Aug.	2.29	12.93	2.11	21.84	2.54	20.01	2.16	25.02	2.16	2.46
26 Aug. - 2 Sept.	1.14	14.07			1.32	21.34	1.90	26.92	0.51	5.97
2 Sept. - 9 Sept.	0.13	14.20	1.27	23.11	0.15	21.49[6]	0.00[7]	26.92	0.25	6.22
9 Sept. - 16 Sept.	2.29	16.48	2.29	25.40	missing				4.19	10.41
16 Sept. - 23 Sept.	1.32[3]	17.80	0.53[3]	25.93	1.40				1.14	11.56
23 Sept. - 30 Sept.					0.25				0.64	12.9
20-27 May 1970			2.03		2.16				2.03	
27 May - 3 June			1.32	3.35	0.64	2.79	2.67		0.89	2.92
3 June - 10 June										
10 June - 17 June			4.90		4.44		13.46		4.06	
17 June - 24 June				8.26		7.24				6.98
24 June - 1 July			2.92	11.18	3.68	10.92		16.13	2.67	9.65
1 July - 8 July	13.14		4.32		6.60		6.22		3.68	
8 July - 15 July				15.49		17.53		22.35		13.34
15 July - 22 July			2.29	17.78[11]	1.90	19.43	1.78	24.13	1.52	14.86
22 July - 29 July			missing		0.00	19.43	0.51	24.64	0.00	14.86
29 July - 5 Aug.	2.56	15.70	1.78		2.31	21.74	1.85	26.49	2.44	17.27
5 Aug. - 12 Aug.	2.95	18.64	3.56		2.95	24.69	2.56	29.06	1.52	18.80
12.Aug. - 19 Aug.	0.96	19.61	0.00		1.22	25.91	1.07	30.12	0.25	19.05
19 Aug. - 26 Aug.	1.88	21.49			2.16	28.07	2.44	32.56		
26 Aug. - 2 Sept.	0.00	21.49	3.56[10]		0.81	28.88			2.54	21.59
2 Sept. - 9 Sept.	0.41	21.89			0.00	28.88	0.28	32.84		
9 Sept. - 16 Sept.	2.97	24.87			4.98	33.86	4.44[12]	37.29		
16 Sept. - 23 Sept.	1.52[9]	26.39			0.41	34.26				

1 Record started 3 June 1970.
2 Cumulative from 1 July 1970.
3 Observation terminated 23 Sept. 1970.
4 Record started 17 June 1970.
5 Chart was changed to 10 July 1970.
6 Cumulative terminated 9 Sept. 1970 due to missing data for following week.
7 Observation terminated 9 Sept. 1970.
8 Record started 5 Aug. 1970.
9 Observation terminated 23 Sept. 1970.
10 Observation terminated 2 Sept. 1970.
11 Cumulation terminated 22 July, due to missing data for period following.
12 Observation terminated 16 Sept. 1970.

TABLE 8. A COMPARISON OF PRECIPITATION (cm) AT THE FAIRBANKS OFFICE OF THE NATIONAL WEATHER SERVICE AND AVERAGE PRECIPITATION ON THE CARIBOU CREEK WATERSHED FOR JUNE, JULY, AUGUST AND SEPTEMBER 1970 AND 1971 (Ford, 1973).

	JUNE		JULY		AUGUST		SEPTEMBER		
	Fair-banks	Caribou Creek	Fair-banks	Caribou Creek	Fair-banks	Caribou Creek	Fair-banks	Caribou Creek	
1	0.05				0.18	0.76			1
2	0.05				0.10				2
3			1.35	0.43	0.36	1.42			3
4				0.05	0.02	0.02	0.02		4
5	0.08		0.02	1.27	0.46	1.50	0.02	0.15	5
6						0.13		0.02	6
7			0.02		0.43	0.61		0.05	7
8			0.20			0.02			8
9									9
10	0.02	0.91	0.30	0.96	0.05	0.30			10
11	0.15				0.23	0.05			11
12					0.13	0.08	0.23	0.71	12
13							0.33	1.70	13
14	0.13	0.76	0.20	0.13				1.02	14
15	0.18	0.20	0.08	0.58		0.05	0.02		15
16	0	0.15	0.33	0.58	0.02	0.53	0.15	0.05	16
17	0.02	0.10					0.33	1.12	17
18			0.61	0.64					18
19			0.28	0.28					19
20			0.13	0.13	0.02	0.05		0.02	20
21	1.12	1.96			0.13	0.25	0.05		21
22	1.09	0.13			0.05	0.71	0.18		22
23	0.05	0.08				0.13	0.02	0.05	23
24	0.96				0.69	1.19		0.13	24
25	0.23			0.05			0.13		25
26	0.58						0.10	0.08	26
27	0.23	0.08							27
28	0.86		0.18				0.02		28
29	0.41	0.41	0.05				0.02		29
30	0.05	2.79	0.15	0.15	1.83	0.91			30
31	—	—	0.66	0.23	0.33				31
TOT	6.53	7.57	4.60	5.49	5.03	8.74	1.65	5.10	TOT
Dep	+3.00	—	-0.08	—	-0.56	—	-1.14	—	Dep

	JUNE		JULY		AUGUST		SEPTEMBER		
	Fair-banks	Caribou Creek	Fair-banks	Caribou Creek	Fair-banks	Caribou Creek	Fair-banks	Caribou Creek	
1			0.69	0.36	0.51	0.20	0.15		1
2			0.02	0.15	0.08	0.46	1.12	1.12	2
3				0.08	0.13	0.71	0.86	1.07	3
4				0.10	0.28	0.23	0.53	0.66	4
5				0.13			NO		5
6					0.10	0.64	DATA		6
7				0.02	0.10	0.82			7
8					0.69	1.98			8
9					1.17	1.60			9
10					0.25	0.89			10
11			0.30	1.52					11
12	0.10		1.90	2.97		0.05			12
13	0.20	0.02	0.61	1.04		0.02			13
14	0.20	0.13	0.20	0.51					14
15				0.05					15
16				0.23					16
17				0.10					17
18	0.02	0.02		0.46					18
19		1.12	1.10	0.13	0.51	0.36			19
20	0.08	0.08	0.08	0.46	1.04	0.30			20
21	0.05	0.91		0.02	0.02				21
22									22
23					0.81	0.89			23
24				0.08					24
25						0.08			25
26									26
27			0.71	1.20					27
28			0.13	0.05					28
29	0.02	0.08	0.24	0.25		0.02			29
30	0.10	0.28	0.05	0.23	0.20	0.18			30
31	—	—	0.23	0.51					31
TOT	0.79	2.64	5.28	10.85	5.89	9.91			TOT
Dep	-2.74	—	+0.61	—	+0.30	—			Dep

Voids = No data (no measureable precip.).

TABLE 9. DAILY PRECIPITATIONN (cm WATER EQUIVALENT) CARIBOU-POKER CREEKS RESEARCH WATERSHED.

Station: Confluence of Caribou and Poker Creeks — Elevation Approximately 221 m

	1973							1974						1975		
Month	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Day																
1			1.19			0.46									0.02	
2		0.61	0.89			0.15				0.71						
3		1.19	0.08	0.02	0.02	0.23				0.46			0.18			
4		0.02	0.05		0.02	0.10						0.23				
5				0.02		0.74						0.10		0.43		
6		0.66	1.70	0.05		0.18			0.25			0.02				
7			0.05		0.02		0.13		0.81			0.05				
8			0.02			0.02			0.15	0.23		0.13	0.08			
9				0.33	0.25					0.51		0.08	0.08	0.10	0.05	
10	0.02	0.43	0.02	2.24	0.08		1.27		0.05	0.02			0.02			
11		0.41	0.41	1.37			0.05		0.29				0.41			
12		0.05	1.14	0.53	0.02	2.18				1.45			0.43			
13			1.22	0.08						0.64						
14		1.27	0.13	0.05	0.05				0.18	0.38		0.36	0.05		0.02	
15			1.22							0.08		0.02	0.41	0.05	0.02	
16		0.05							0.15	0.10	0.36	0.25		0.02		
17			0.02	0.02								0.48				
18	0.30		0.28	0.41					—	—	—	—	—	—		
19			1.98				0.18		0.25	0.20						0.20
20	0.02		0.38	0.15			0.08				0.02					
21		0.71		2.08	0.02						0.28					
22				0.94							0.13					
23	0.10	0.10			0.13				0.51		0.56	0.10	0.02			
24		0.15	0.02		0.02				0.10		0.28		0.13	0.02		
25	0.61			0.10	0.02				0.02		0.38					
26	—	—	—	—	—					0.02	0.10			0.02	0.56	
27			0.02	1.40						0.41				0.02	0.74	
28		0.05	0.36		0.08					1.02					0.15	
29		0.02	1.47		0.02		0.28		—	—	—	—	—	—	0.02	
30	0.23	0.05	0.05		0.05				0.23		0.08					
31	0.05		0.20	0.02									0.20			
TOTAL	1.35	5.79	13.16	9.83	1.40	4.06	1.98	37.82	3.00	6.22	2.18	1.83	1.81	0.89	1.63	0.20 17.65

TABLE 10. PRECIPITATION SUMMARY, SUBDRAINAGE C-3, 640 M ELEVATION. SUMMER 1974.

Period		Incremental Precipitation, cm
1-31 May		2.8
1-30 June		4.8
1-31 July		4.0
1-31 August		6.9
1-31 September		2.4
	Total	18.4

TABLE 11. PRECIPITATION SUMMARY, 28 JUNE 1973 - 6 MARCH 1974, CARIBOU CREEK VALLEY. UNIVERSAL WEIGHING GAGE AT USGS STREAM GAGE.

Period		Incremental Precipitation, cm
29 June - 18 July 1973		10.2
19 July - 15 August		8.1
16 August - 26 August		2.7
27 August - 3 October		1.3
4 October - 17 October		2.7
18 October - 22 October		0.1
22 October - 6 November		missing
7 November - 14 November		2.4
15 November - 28 November		0.4
29 November - 11 December		0.1
12 December - 25 December		0.2
26 December - 31 December 1973		0.0
1 January 1974 - 8 January		0.1
9 January - 31 January		0.4
1 February - 5 February		0.4
6 February - 19 February		0.8
20 February - 28 February		0.5
1 March - 5 March		0.6
6 March - 19 March		0.3
	Total	31.1

TABLE 12. SUMMER RAINFALL IN CARIBOU BASIN.

Station	Elev. (m)	pptn. (cm)	Station	Elev. (m)	pptn. (cm)
Haystack Mt.	768	23.3	Haystack Mt.	738	21.6
C-2	335(S)	25.4	C-2	335(S)	37.3
C-2	448(S)	17.7	C-2	488(S)	34.3
C-3	488(N)	30.1	C-3	640(N)	26.9
Fairbanks	132	12.9	Fairbanks	132	18.9
			Caribou Cr.	274	25.9

Figure 12. Wind shield on precipitation gage on Caribou Peak.

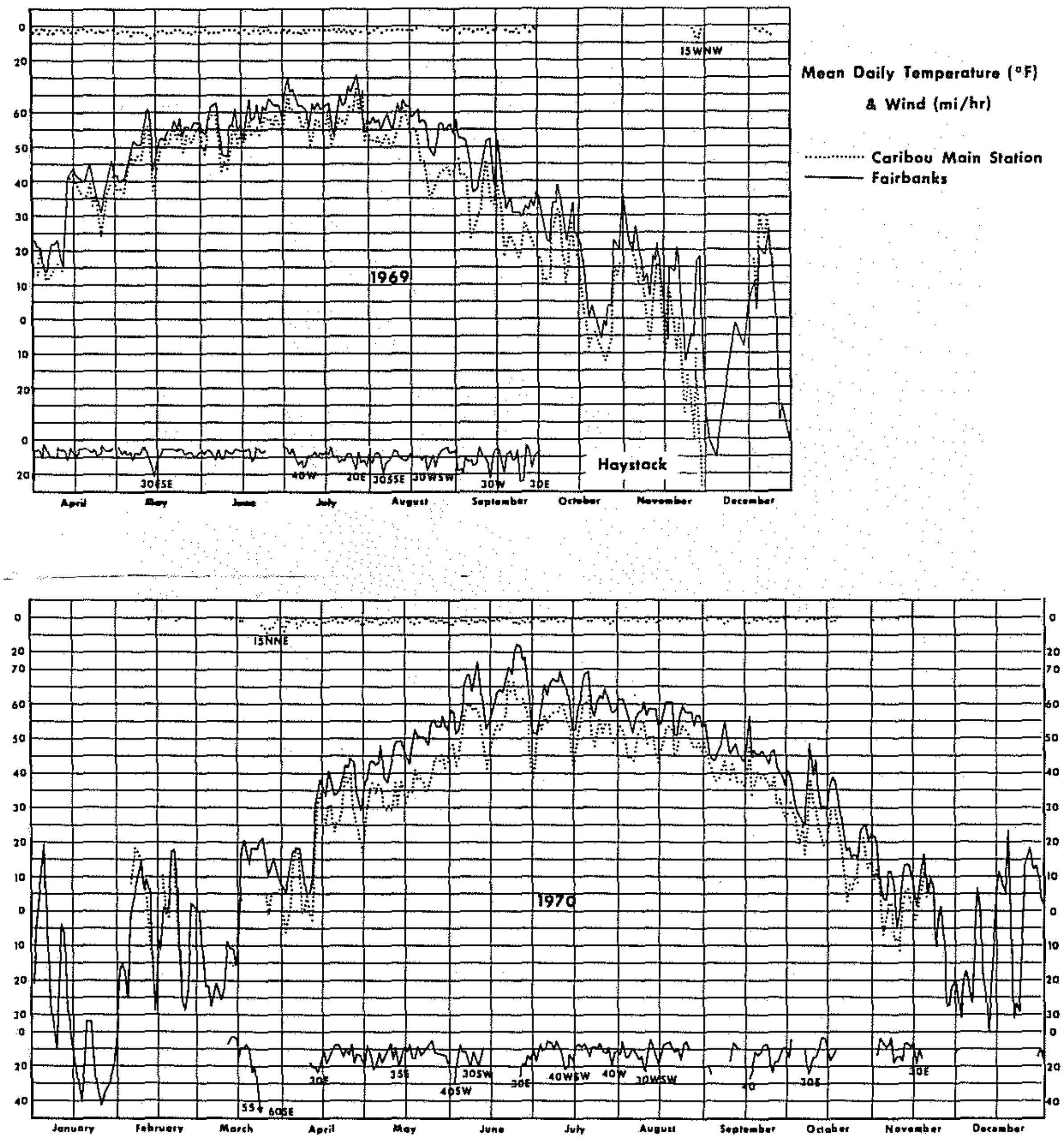

Figure 13. Mean daily temperature of Fairbanks and Caribou main station, and wind at the Haystack Mountain and Caribou main station for 1969 and 1970.

Variability among the Caribou Creek stations does not appear to be solely the result of orographic effects in individual basins, but also stems from an overall convective effect over these highlands, with individual storm cells passing over a basin at random. Valley stations in the highlands receive about as much summer rainfall as higher slopes because the overall convective rainfall is not selctive where it falls. But once a cell starts to precipitate, it is carried randomly across ridges and valleys. The lower summer rainfall recorded on Haystack Mountain may be biased by winds, since the gage was not shielded and this peak is usually windy compared to lower stations. Recent installations of wind shields on Caribou Peak and Helmer's Ridge (Figure 12) should result in more reliable summer and winter precipitation data.

All evidence cited here suggests that summer rainfall is higher in the highlands of interior Alaska than in broad valleys, as represented by Fairbanks. This higher rainfall is attributed to the orographic effect causing convective storms to form over highlands more effectively than over large broad lowlands. Within the highlands, local orographic effects are apparently not sufficient to cause variability among stations because, once convective precipitation starts, it seems to be distributed randomly over valleys and slopes as a particular cell moves.

Temperature and Wind

Unlike rainfall, temperature patterns of these watersheds closely resemble those of Fairbanks. Mean daily temperatures for Fairbanks and the main site (as plotted in Figure 13 for 1970 and 1971) illustrate how closely temperatures at both stations followed one another during daily and seasonal variations. Mean temperature at Fairbanks was several degrees warmer than in the Caribou Creek valley, probably because the watershed site is about 150 m higher than Fairbanks. The close correspondence of maxima and minima in these curves indicates that the air masses respond as a uniform fluid and that temperatures at Fairbanks might conceivably be extrapolated to Caribou Creek. Complete winter means are not available for the main site because of maintenance and logistical problems during the extreme winter cold. The Fairbanks station receives close supervision to ensure that continuous records are obtained. Data gaps at Caribou Creek might be filled in from Fairbanks data by careful extrapolation based on such paired curves as shown in Figure 13.

Average wind speeds for the main site and Haystack Mountain are also shown in Figure 13 to compare winds in the valley with those of the 762 m peak. Winds for April through September are light in the valley but moderate to strong on the peak. At no time during this period did winds in the valley exceed 6.7 m/sec; averages were much lower. During the same period winds on Haystack Mountain were averaging much higher, with gusts of 13.4 to 17.9 m/sec. Winter records for wind are sparse for the same reason that caused the gaps in temperature data.

Figure 14 compares mean daily temperatures and winds for Haystack Mountain and Caribou Peak (elevations 770 and 773 m, respectively). In 1969 temperatures on Haystack tended to be a few degrees higher than for Caribou, with maxima and minima occurring at the same time; 1970 data indicated higher temperatures on Caribou Peak, although the patterns are nearly identical.

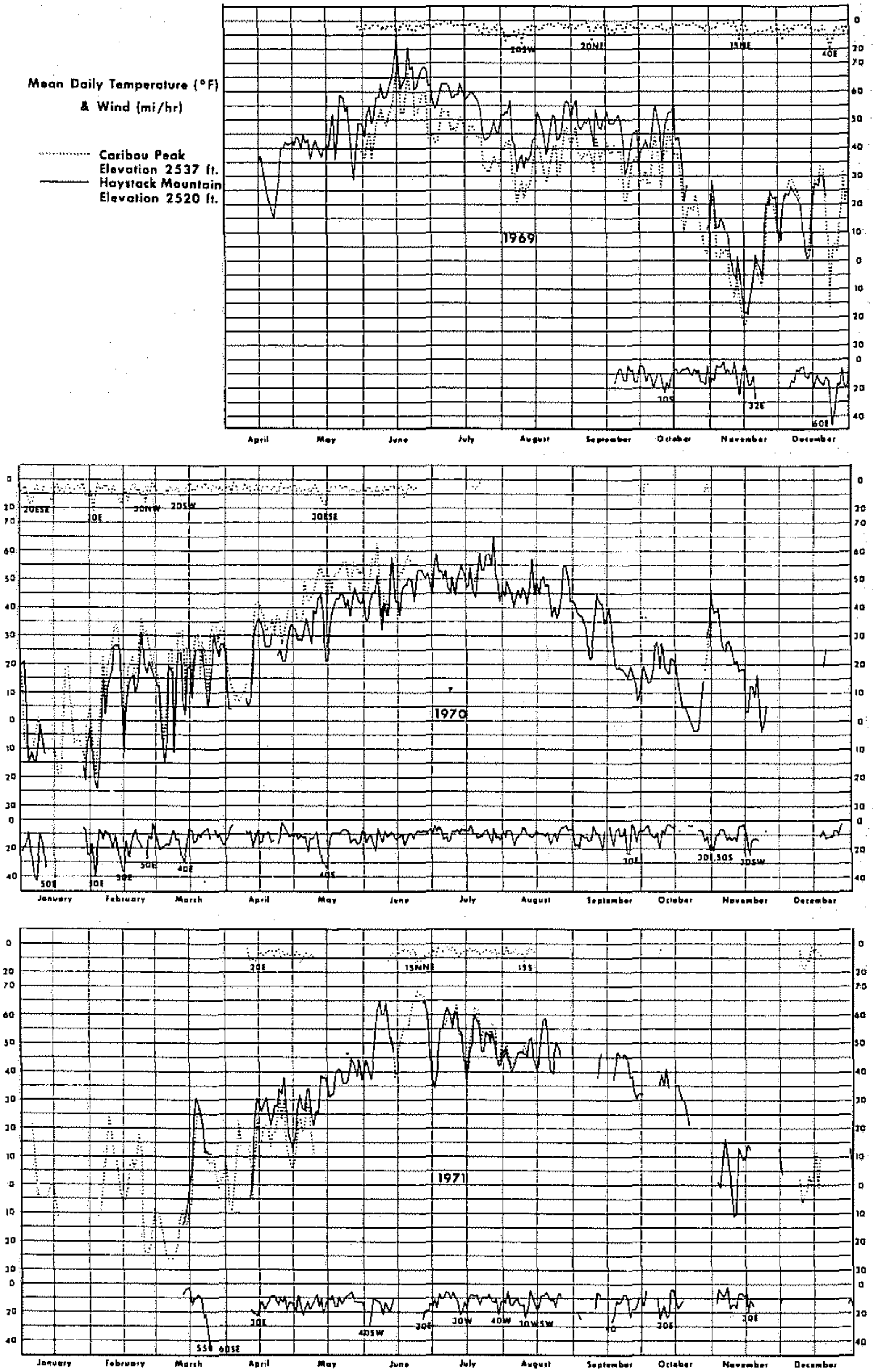

Figure 14. Mean daily temperature and winds for Caribou Peak and Haystack Mountain for 1969, 1970, and 1971 (note the similarity of elevation).

Winds at Haystack are generally stronger than at Caribou. Wind speeds averaging 8.9 m/sec with gusts of 17.9 to 22.3 m/sec are common on Haystack, especially in winter. On the other hand, winds at Caribou average less than 4.5 m/sec, with a maximum recorded gust of 17.9 m/sec and most in the 8.9 to 13.4 m/sec range. A possible explanation for wind speed differences between peaks may be the shapes and exposure to modifying influences. Caribou Peak lies nearly in the center of the watershed and has broad, gently sloping topography, whereas Haystack Mountain is on the southwestern edge of the watershed and has moderate to steep slopes on all sides. A valley several miles wide lies south and west of Haystack Mountain whereas Caribou Peak is protected on three sides by highlands separated from it by narrow valleys. The dominant direction of peak gusts is from the east at both peaks.

In Figure 15, mean daily temperatures at two elevations are compared for subbasin C-2. These curves show that temperatures at 488 m elevation tend to be higher than at 405 m in the valley, but the variance is slight and not consistent. This suggests lack of a pronounced temperature inversion with elevation, such as commonly occurs at Fairbanks. In fact, as shown for 1970, the coldest temperatures in winter are at the higher elevation. Data for 1971 show a tendency for higher temperature at 488 m, although highs are within a few degrees of one another and occur at approximately the same time.

Temperature data plotted on Figure 16 for C-3, a north-facing slope, permit an interpretation similar to that for C-2. There was no pronounced inversion for the period shown and the air mass appears to respond uniformly to factors causing temperature variation.

Comparing data plotted for C-2 with that of C-3 permits an evaluation of north versus south for two slope aspects. The data available suggest that mean temperatures at instrument height were not significantly different between the opposite slopes. Yet, the north slope had permafrost, which was absent on the south slope. In their analysis of climatic parameters, Slaughter and Long (1974) pointed out that the daily range of June temperature is greater on the south-facing slope than on the north (20.6^{o}C compared to 12.1^{o}C). Such higher temperatures during the day may provide enough energy to prevent permafrost from forming on these south-facing slopes. Evidently, as Slaughter and Long point out, air temperature at the standard instrument height is not measuring the factor that influences whether or not a substrate remains frozen during the warm season. Some factor in the microclimate must be the dominant element controlling the presence or absence of permafrost.

Soil temperatures at the interface of the organic with the mineral soil horizons are plotted in Figures 15 and 16 for basins C-2 and C-3 (south versus north aspect). This comparison shows that there is a distinct difference in temperature at this interface. Soil temperature on the south-facing slope (Figure 15A) at the end of summer in 1969 did not drop to freezing until 24 September; soil temperature on the north-facing slope (Figure 16A) reached freezing on August 10 and remained at or below freezing through the rest of the calendar year. Fluctuations of air temperatures are reflected in similar fluctuations in the soil.

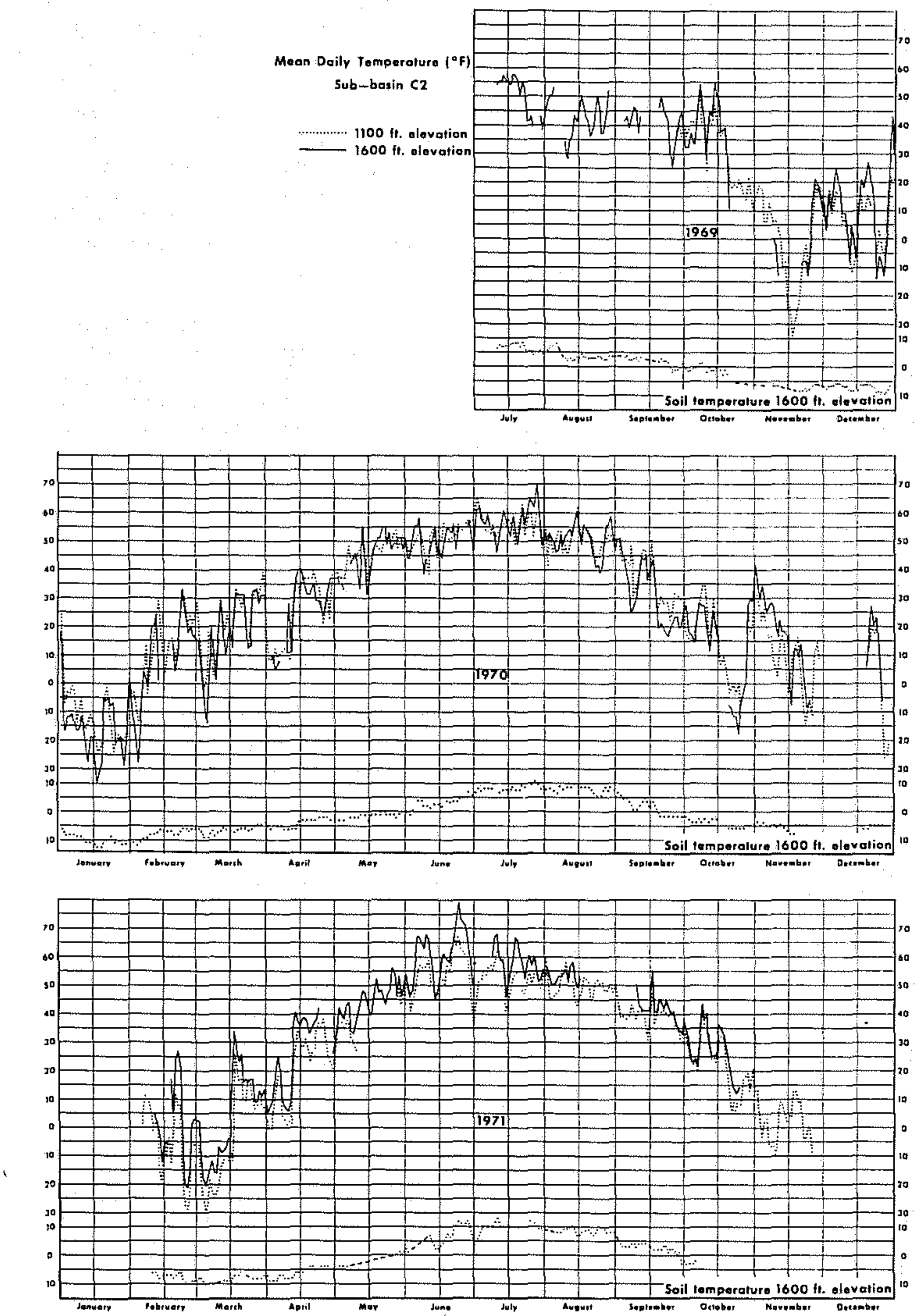

Figure 15. Mean daily air temperature in subbasin C-2 at two elevations, soil temperature °C at 1,600 ft (488 m) elevation.

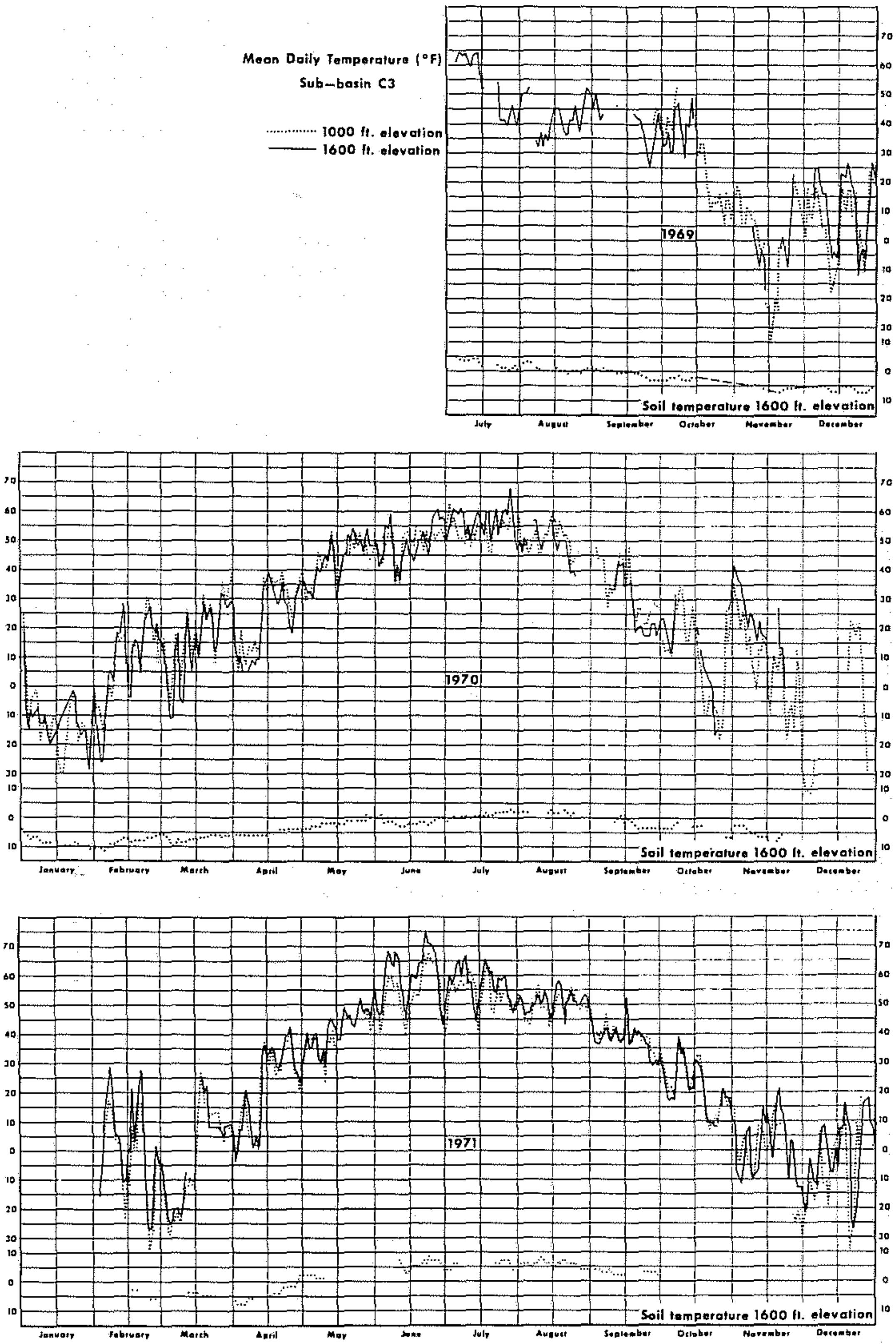

Figure 16. Mean daily air temperature in subbasin C-3 at two elevations, soil temperature °C at 1,600 ft (488 m) elevation.

However, the temperature changes in the soil are much more subdued. Maximum and minimum temperatures at the organic mineral soil interface are probably strongly influenced by the thickness and moisture content of the overlying moss layer. This will not be discussed here because data on this aspect of soil temperature are not yet available. Future work delving into this parameter of microclimatology should thoroughly evaluate these effects.

Discontinuous records of soil temperature for 1970 are shown in Figures 15 and 16B for both exposures. Minimum temperatures during winter are nearly the same at both stations, although soil temperature rose to freezing on the north exposure a few days earlier than on the south but then dropped, never rising above 1^{o}C until 15 July. On the other hand, the rise continued once the soil temperature on the south exposure rose above freezing, reaching 10^{o}C on 27 July. The soil remained above freezing until 19 September. In contrast, temperatures on the north exposure never exceeded 3^{o}C and were below freezing by 10 September. Thus, it becomes apparent that, although air temperatures at both exposures are nearly identical at standard instrument height, the soil microclimate is considerably different, being warmer for a longer period on the south compared to north exposure. Data for 1971 show similar trends although the data are less continuous.

These observations lead to the same conclusions as those of Slaughter and Long (1974), that measuring air temperature at the standard instrument height is inadequate to describe microclimate. Energy availability, indicated here by soil temperature, must permit permafrost on north slopes but allow thawing on south slopes.

Based on this interpretation of the somewhat sketchy data, several tentative conclusions may be drawn which in turn lead to some suggestions or recommendations for further work. Data for summer rainfall clearly indicate that the research watershed received more precipitation that Fairbanks, although Fairbanks records are commonly cited when describing the climatology of interior Alaska. Available data suggest that upland areas, as represented by the watershed basin complex, receive nearer 50 cm of total precipitation compared to the long-range average of 30.5 cm for Fairbanks. This increase is attributed to the orographic effect of uplands as opposed to broad, low lands such as the Tanana Valley. Santeford (1976) developed equations to predict summer and winter precipitation at various elevations from precipitation data from Fairbanks. These are preliminary and require further testing, but it is an attempt to extrapolate data from a completely maintained weather station to more distant k areas where weather and logistics prevent gathering of continuous records. Data from individual basins suggest that orographic effects do not significantly affect the precipitation pattern but have an overall effect when compared to broad lowlands.

With these thoughts in mind, it is suggested that perhaps an intense network of precipitation gages, sited with elevation, may be counterproductive when considered for small basins. Efforts might be expended in continuous maintenance of fewer, carefully sited stations to ensure that gaps in records do not appear. Thoughtful extrapolation of these records could be used to expand a given storm event. Before a final decision is made on this aspect of climatology, we recommend that this hypothesis be tested with a network of gages in all basins during several storm events.

Temperature patterns for all sites in the watershed are closely correlated with temperatures at Fairbanks. Although absolute numbers may be somewhat different, careful extrapolation of data from Fairbanks might be used to predict temperatures at selected sites in the watersheds. Because of air drainage, summer temperatures in a narrow valley may be cooler than in Fairbanks, which lies on the edge of a broad plain. No comparative data are available to compare winter temperatures. Fairbanks often develops a strong temperature inversion during the winter that does not appear to develop intensely in these smaller basins. Available data from the research watersheds may have been measured at elevations different from that where an inversion would form. Field observations suggest that there is often a winter inversion between the junction of Caribou and Poker creeks, and Caribou Peak. However, no data are available at this writing to verify the magnitude of the inversion. Conditions for strong inversions may not be present in small, narrow valleys but in larger valleys with greater total relief (such as between the Caribou-Poker creeks confluence and Caribou Peak), topography provides conditions permitting inversions to develop.

Air temperature patterns of northern versus southern exposures are similar and, at a given elevation on a slope, nearly identical in mean values. Soil temperatures, on the other hand, show a correspondence to exposure, illustrating that factors in the microclimate and topography control the formation of permafrost--and consequently plant growth, soil microbiological activity, and other soil phenomena such as soil heat flux. Synoptic weather patterns, such as those recorded at Fairbanks, control the broad patterns at the watershed; smaller deviations result from local factors.

Looking to the future, it appears that careful thought should be given toward eliminating some of the temperature measurements and increasing microclimate measurements. Thus, data on air temperature at various elevations measured at standard instrument heights might be replaced or complemented by an array of sensors to measure microclimate at selected locations. It is difficult to obtain continuous winter records with standard instruments and procedures, as is indicated by the data gaps noted in this discussion. Valley climate stations might be abandoned except for a few carefully selected sites. The weather station on Haystack Mountain might be eliminated and strenuous effort made to obtain reliable, continuous records on Caribou Peak and Helmer's Ridge, both of which are centrally located within the watershed. Perhaps a few master stations would monitor ambient weather elements; all other installations would concentrate on microclimatology.

STREAMFLOW

Streamflow constitutes the apparent integrated response of the catchment system to water input upstream of the point of measurement. For a given valley, streamflow and groundwater outflow compose the basic yield; streamflow alone is the more dynamic and more easily measured variable of the low order streams which dominate the Caribou-Poker creek catchment. The arbitrary decision has been made to concentrate measurements on surface discharge-streamflow.

Existence of apparently uninterrupted permafrost in all valleys suggests that groundwater yield might be relatively low, and presumably constant. In the absence of drilling capability to establish (and maintain unfrozen) observation wells through the permafrost in these valleys, as well as to define geologic conditions in the stream valleys, the simplifying assumption is that surface water measurements will suffice for evaluating comparative flow regimes among subbasins, and for evaluating stream system response to imposition of watershed management practices.

Continuous-record streamflow measurement stations were installed on Caribou Creek (1969)(Figure 17) and Poker Creek (1970) by the Water Resources Division, U.S. Geological Survey. Daily streamflow data from those stations are included here as Appendix A. In addition, a number of point streamflow measurements have been made in the various watershed subdrainages. These individual observations, acquired with a Price current meter (Figure 18), are given in Table 13.

It has been difficult to obtain either continuous (during summer) streamflow records on the main stream, or regularly spaced current meter measurements in subdrainages. Problems relate primarily to difficulty of access for site servicing, and to severe aufeis during late winter and spring at the continuous-measurement stations (Figure 19). Aufeis has often made recording of water stage impossible (Figure 20). Nonetheless, it is now possible to derive some information on hydrologic behavior from the available data.

Discharge typically decreases throughout the winter months from October until breakup in late April or May. A slight increase in discharge commonly occurs in both streams just prior to breakup, with maximum discharge occurring at breakup. Total runoff at this time is virtually impossible to measure, because water is diverted out of the stream channel by ice, and follows a wide variety of routes down the valley (Figure 21). Figure 22 shows a summer view of the same confluence.

Discharge during the winter can be considered near base flow, because all water in the channel is then derived from groundwater. Monthly summaries of base flow (Table 14) show a wide variability for both streams, from 18,502 ha-m* to 58,960 ha-m for Caribou Creek, and from 46,749 to 145,551 ha-m for Poker Creek; these maxima and minima occurred in the same year (1970) in both basins.

Discharge fluctuates during summer in response to storms; high runoff in one basin is usually coincident with similar runoff in the other. Local convective storm events may cause a rise in discharge of one basin over the other but, over a month or more, these local events tend to smooth out.

*ha-m (hectare-meter) is the metric equivalent of ac-ft (acre-feet); ha-m = ac-ft x 8.1070844; ac-ft = ha-m x 0.123350.

Figure 17. Gaging station on Caribou Creek main stem, established in 1969 by USGS.

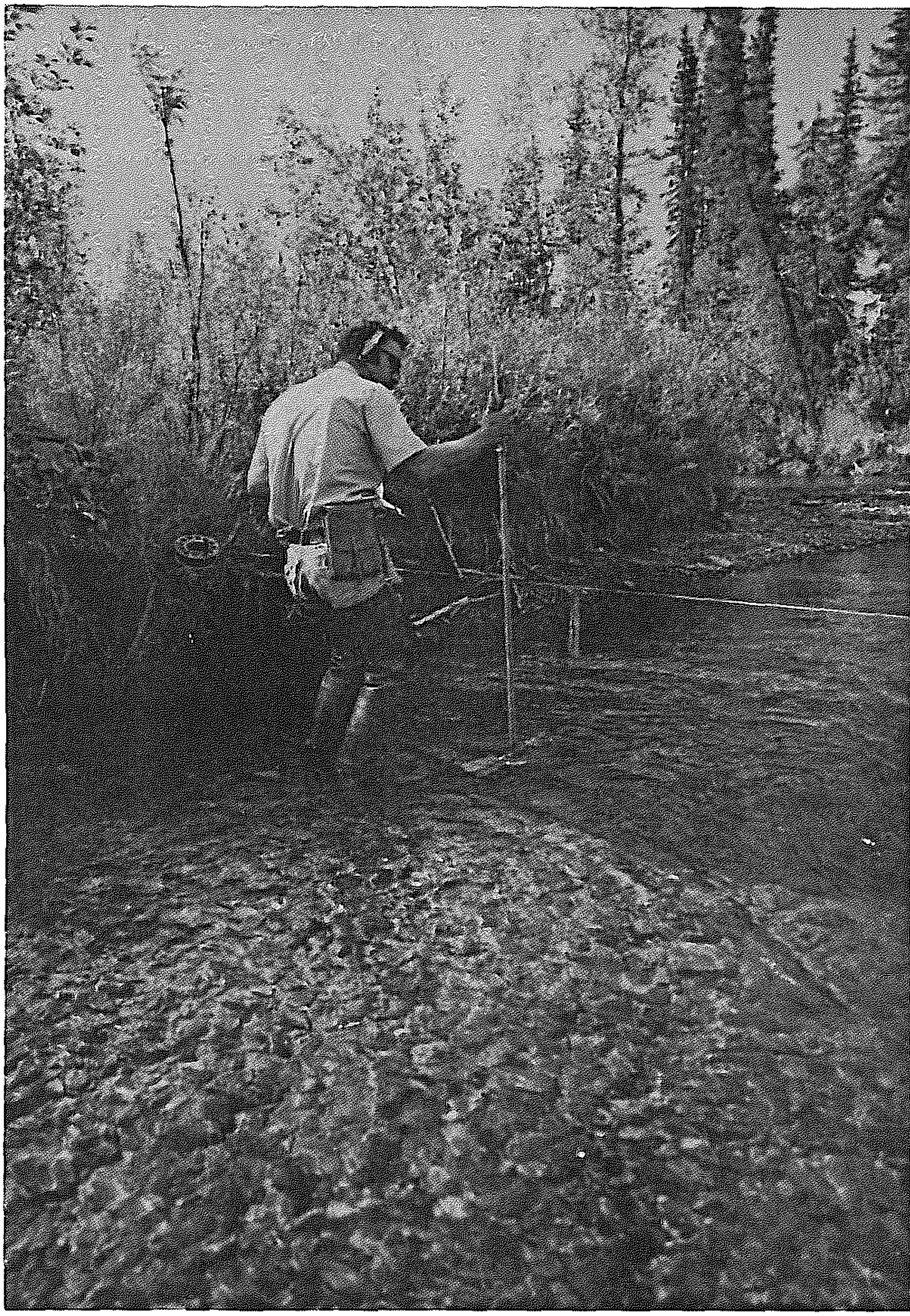

Figure 18. Stream gaging on Caribou-Poker Creek near Chatanika River, 1971.

Figure 19. An icing actively forming in upper Poker Creek valley, 1975.

Figure 20. A water stage recorder became encased in ice when icing overcame the gaging station on Poker Creek in 1974. (This instrument was removed for thawing and returned to service.)

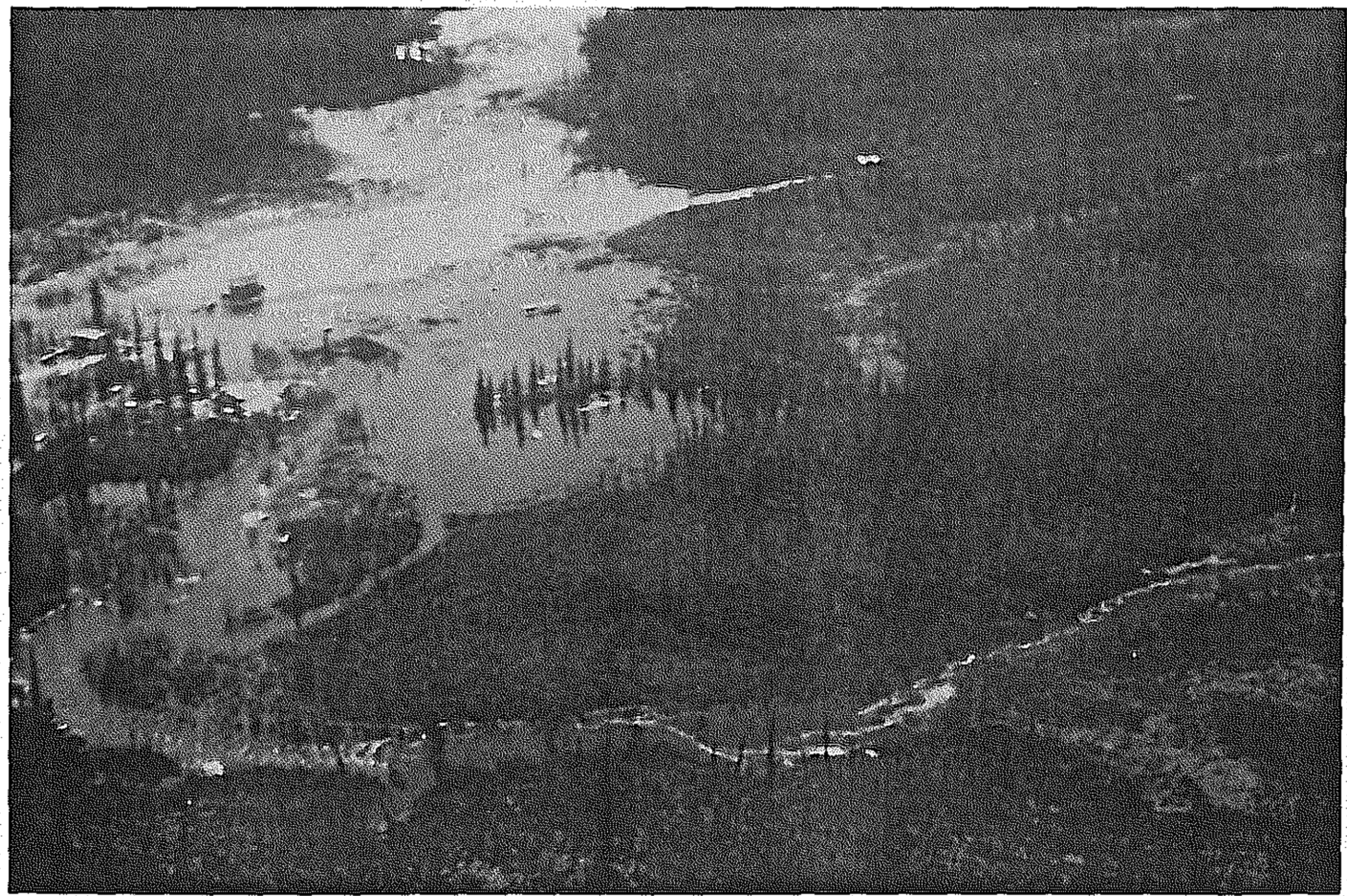

Figure 21. Confluence of Caribou Creek and Poker Creek at breakup. Poker Creek flows to the left at bottom and Caribou Creek flows toward the viewer at top. Both flow out of the picture to the left of lab trailer.

Figure 22. Confluence of Caribou Creek and Poker Creek in summer before the lab trailer was moved to the site (looking north-westward). Caribou Creek flows from upper left, Poker Creek from middle right. They join in the center and flow out at lower right. At breakup (Figure 21), this entire portion of the valley was covered with a mass of ice and water.

TABLE 13. DISCHARGE (m^3/sec) AND YIELD (m^3/sec/km^2) FOR STREAMS OF CARIBOU-POKER CREEKS WATERSHED (1970 AND 1971-72).

Basin	C2			C3			C2			C3			C4			PM P4		
	Date	Disc.[1]	Yield[2]	Date	Disc.	Yield	Date	Disc.	Yield	Date	Disc.	Yield	Date	Disc.	Yield	Date	Disc.	Yield
				4/14	0.004	0.001	7/15	0.037	0.007	7/8	0.034	0.007	7/23	0.050	0.005	7/22	0.187	0.007
				4/22	0.007	0.001	7/21	0.042	0.008	7/21	0.028	0.006	7/30	0.004	0.005	7/28	0.131	0.005
				4/29	0.017	0.003	8/6	0.053	0.010	8/6	0.135	0.028	8/4	0.054	0.006	8/4	0.192	0.007
				5/6	0.022	0.005	8/12	0.036	0.007	8/12	0.025	0.005	8/13	0.053	0.006	8/13	0.201	0.007
				5/13	0.044	0.030	8/19	0.032	0.006	8/19	0.013	0.003	8/19	0.053	0.006	8/20	0.160	0.006
				5/20	0.022	0.004	8/26	0.036	0.007	8/26	0.044	0.009	8/27	0.065	0.007	8/27	0.214	0.008
				5/27	0.118	0.025	9/2	0.031	0.006	9/2	0.033	0.007	9/3	0.057	0.006	9/3	0.195	0.007
	6/3	0.019	0.004	6/3	0.068	0.014	9/9	0.036	0.007	9/9	0.020	0.004	9/11	0.056	0.006	9/10	0.172	0.006
	6/10	0.014	0.033	6/10	0.006	0.001												
	6/17	0.016	0.003	6/17	0.137	0.028												
	6/25	0.022	0.004	6/24	0.061	0.014												
	7/1	0.048	0.009	7/1	0.212	0.044												

P4			P6			CM[3]			PM			PC		
Date	Disc.	Yield	Date	Disc.	Yield	Date	Disc.	Yield	Date	Disc.	Yield	Date	Disc.	Yield
7/22	0.046	0.004	7/22	0.031	0.004	7/23	0.252	0.010	7/23	0.316	0.005	7/23	0.570	0.006
7/28	0.041	0.004	7/28	0.018	0.003	7/30	0.215	0.005	7/30	0.240	0.004	7/30	0.455	0.004
8/4	0.045	0.004	8/4	0.025	0.004	8/6	0.736	0.017	8/6	0.088	0.018	8/6	0.825	0.018
8/13	0.058	0.005	8/13	0.031	0.004	8/13	0.239	0.006	8/13	0.353	0.006	8/13	0.592	0.006
8/20	0.050	0.004	8/20	0.025	0.004	8/19	0.232	0.006	8/19	0.296	0.005	8/19	0.528	0.005
8/27	0.063	0.006	8/27	0.031	0.005	8/27	0.303	0.007	8/27	0.369	0.006	8/27	0.672	0.006
9/3	0.058	0.005	9/3	0.030	0.004	9/3	0.261	0.006	9/3	0.307	0.006	9/3	0.598	0.006
9/10	0.066	0.006	9/10	0.025	0.004	9/11	0.240	0.006	9/11	0.266	0.004	9/11	0.505	0.005

Date		8/14/71		9/8/71		9/29/71		6/1/72		6/29/72		8/22/72		
Stream	Area, km^2	Disc.[4]	Yield[5]	Disc.	Yield	Disc.	Yield	Disc.	Yield	Disc.	Yield	Disc.	Yield	Aver. Yield
C1	6.66	0.156	0.40	0.088	0.023	0.051	0.013	0.139	0.037	0.062	0.016	0.053	0.014	0.024
C2	5.07	0.224	0.077	0.074	0.025	—	—	0.096	0.033	0.053	0.017	0.031	0.011	0.038
C3	4.74	0.122	0.044	0.085	0.031	0.048	0.018	0.096	0.036	0.028	0.010	0.037	0.014	0.025
C4	11.29	0.158	0.025	0.170	0.027	0.116	0.018	0.116	0.018	0.071	0.011	0.068	0.010	0.018
P1	14.59	0.396	0.048	0.229	0.027	0.153	0.018	0.507	0.060	0.122	0.014	0.142	0.017	0.031
P2	6.66	0.382	0.100	0.110	0.029	0.063	0.016	0.317	0.083	0.079	0.021	0.037	0.010	0.043
P4	11.26	.235	0.037	0.158	0.044	0.113	0.018	0.275	0.042	0.116	0.018	0.108	0.016	0.029
P6	6.81	0.125	0.033	0.091	0.023	0.059	0.015	0.122	0.031	0.062	0.016	0.057	0.014	0.022
CM	41.27	0.714	0.031	0.578	0.025	0.181	0.008	0.784	0.033	0.260	0.011	0.340	0.014	0.020
PM	59.08	1.147	0.035	0.745	0.021	0.244	0.007	1.396	0.040	0.498	0.015	0.402	0.012	0.022
PC	100.35	1.861	0.033	1.322	0.023	0.425	0.007	2.152	0.037	0.759	0.013	0.742	0.013	0.021

1 Measured by USACRREL with pygmy meter and wading rod, data from Technical Report (Slaughter, 1972).
2 Because the units of volume are large compared to the size of the streams, a more realistic unit, litre/sec, may be derived by moving the decimal 3 points to the right.
3 Calculated by subtracting discharge of Poker above Caribou from discharge of Poker below Caribou confluence.
4 Measured by EPA personnel with a standard Gurley meter and wading rod, data from Lotspeich et al. (1976), Working Paper #30, Arctic Environmental Research Center, College, Alaska.
5 Same note as note 2.

TABLE 14. DISCHARGE VOLUMES (ha-m) FROM USGS RECORDS FOR CARIBOU-POKER RESEARCH WATERSHED BY WATER YEARS.

Mo. Water yr.	Caribou[1]								Poker							
	Oct.	April	May	June	July	Aug.	Sept.	Total	Oct.	April	May	June	July	Aug	Sept.	Total
1969-70	27.1	13.7	48.3	45.6	67.8	51.2	58.7	384.1	—	—	—	—	—	—	—	—
1970-71	32.8	12.6	183.5	105.6	103.5	146.8	74.4	732.8	—	—	—	—	—	—	—	—
1971-72	58.5	10.4	193.3	55.4	46.6	55.5	56.3	578.6	144.4	48.6	458.8	97.7	97.0	145.6	152.9	1370.1
1972-73	40.4	21.9	126.0	54.1	71.1	71.1	55.5	555.4	103.1	55.2	296.0	133.3	157.8	187.2	130.9	1343.2
1973-74	36.8	10.8	81.7	23.1	17.6	19.6	17.4	275.2	86.6	37.1	236.1	95.4	68.9	75.8	73.5	853.9
1974-75	18.4	17.1	148.0	20.7	305	41.2	43.1	358.4	46.4	20.2	330.3	51.4	230.0	133.3	130.9	987.2

1 Does not include discharge from C4.

Personnel from the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) measured stream discharge in a number of tributaries in summer 1970. This was a strenuous effort, because access to the Poker Creek basin was possible only by foot. Readings were made at approximately weekly intervals for three tributaries in Caribou Creek basin from April to early September and for two tributaries of Poker Creek basin from late July to early September. In addition to the tributaries, discharge was measured on the main stem of Poker Creek. These data are included in Table 15.

A storm in the first week of August 1970 illustrates the weakness of not having continuous records, if streamflows of a group of basins are to be compared. On August 4, discharge measurements were made in C-4, Poker Creek above P-4, P-4, and P-6, while all were flowing at slightly higher rates than for the previous week. On August 6, discharge was measured in C-2, C-3, and at the confluence of Poker and Caribou creeks; flow from C-3 and the main streams of Poker and Caribou creeks was about four times that of the previous week. Discharge from C-2 measured on the same day (August 6), showed an increase of only 0.01 m^3 or 27% over the previous week, compared to 400% increases for C-4 and the main streams of Poker and Caribou creeks. In addition to the need for continuous measurements, these data indicate that all portions of a watershed complex do not necessarily receive equal precipitation on a given day--even when two basins are contiguous (C-2 versus C-4 in this case).

It was intuitively supposed that there might be a difference in summer streamflow patterns between low order streams dominated by permafrost (that is, largely north aspect) and those largely free from permafrost (primarily south aspect). Such a contrast, representing the two extremes in ground condition and reflected in differences in soil temperature and vegetative cover, was investigated in subdrainages C-2 (south aspect) and C-3 (north aspect) of Caribou Creek. Current-meter measurements of streamflow for five summers were converted to unit area streamflow, and plotted (Figure 23). Consistent differences are apparent; the north-facing, permafrost-dominated stream (C-3) shows a "flashier" pattern with higher high flows, and lower low flows, relative to the south aspect catchment (C-2). This probably reflects the widespread permafrost-underlain soils in subdrainages C-3, which are cool (providing lower evapotranspiration) and essentially impervious to downward infiltration of water. South-facing slopes, free from permafrost, have generally deeper soil mantles, are more capable of vertical infiltration from incoming precipitation, and are generally warmer with potential for higher evapotranspiration. As volumes/unit area show (calculated from 1971-72 summer data), two subbasins with the least permafrost (C-2 and P-2) had the greatest yield, suggesting that aspect is an important factor to consider when evaluating hydrology in cold climates.

Streamflow measurements at the main valley stations (Caribou Creek and Poker Creek gages) reflect the integrated response to inputs, upstream of their respective measurement points, of subdrainages which are south facing, north facing, and a variety of combinations. Streamflow patterns in the main streams would thus be expected to show less clearly the effects of frozen ground and deep moss layers or, conversely, of unfrozen ground and shallow moss layers. Nevertheless, the effects of

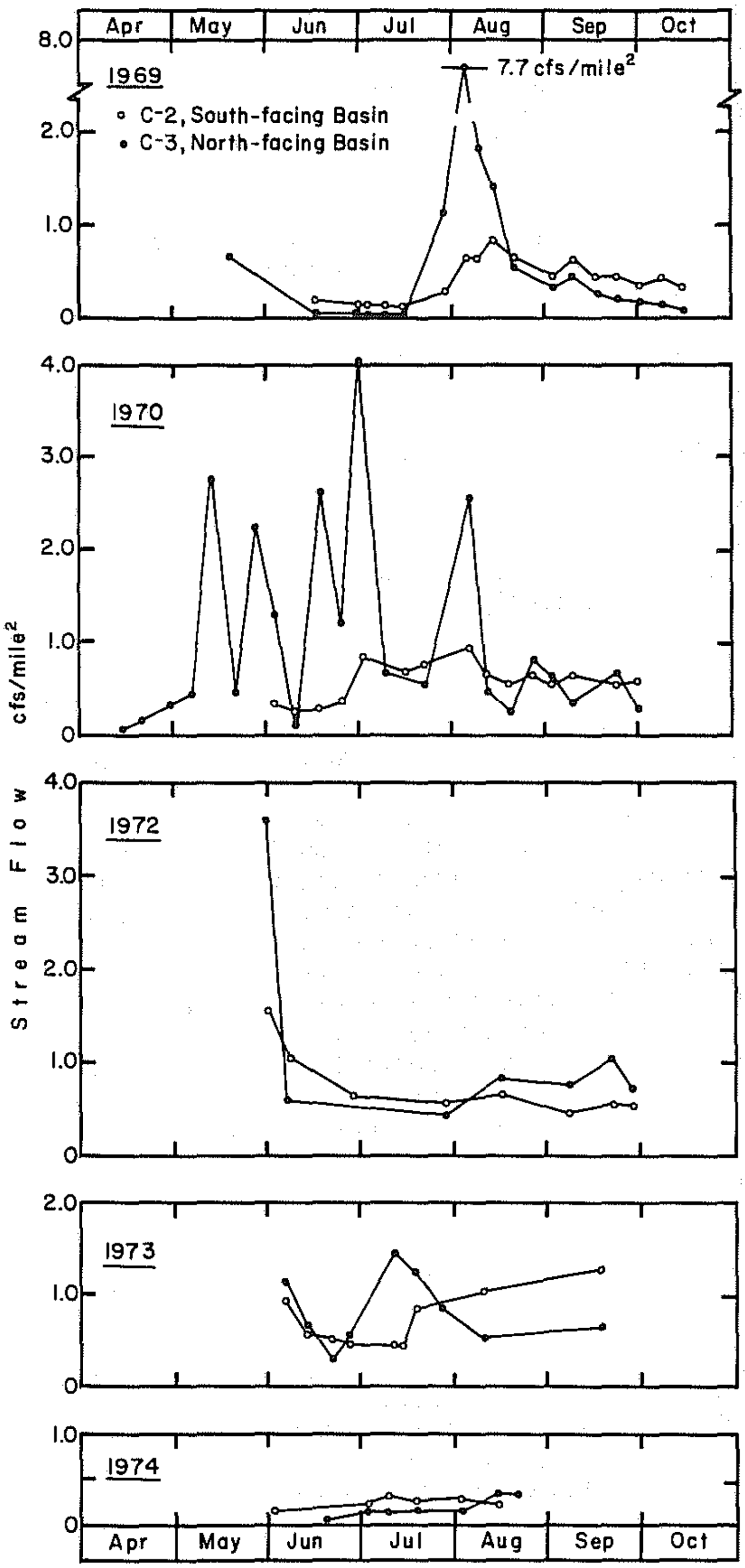

Figure 23. Five years of stream flow records from C-2 (a south-facing basin) and C-3 (a north-facing basin).

large areas of permafrost-underlain soil, in combination with deep layers of surficial moss which are virtually continuous over many slopes, might be expected to dominate the total stream response pattern. Dingman (1971) determined this for a 1.79 km^2 drainage basin which was largely permafrost-underlain. Ford (1973), working with available Caribou Creek data, again suggested that hydrograph recessions for Caribou Creek (as at Glenn Creek) are very long, with low slopes, in response to a delaying action that deep moss layers exert on overland flows. Dingman, MacIntosh and Bredthauer (unpublished) have since investigated Caribou Creek flow data in more detail, utilizing the added information available through 1975. Their conclusions, consistent with earlier results, point to the very important role of the ubiquitous moss layers in regulating summer streamflow in subarctic basins.

The streamflow data now available also permit a preliminary determination of the "representativeness" of the research watershed in terms of general runoff patterns. In Figure 24, streamflow data from five years are plotted for Caribou Creek, Poker Creek, and three measurement points in the Chena River basin (located southeast of the research watershed). Even casual inspection of these hydrographs indicates the similarity in annual regimen between the streams of the research area and the much larger Little Chena and Chena rivers. Timing of flow peaks, and length and rates of recession are in general accord. This supports the contention that the research watershed reasonably represents a larger area of the Yukon-Tanana Uplands in terms of hydrologic behavior.

PRECIPITATION-RUNOFF RELATIONSHIPS

The previous section discussed streamflows in some detail; this section will describe the interrelationships. Although it is generally conceded that watershed hydrology in high latitudes (where permafrost is discontinuous) is quite different from that of temperate regions, Dingman's (1971) work on the Glenn Creek watershed near Fairbanks, Alaska, was the first attempt to accurately describe the hydrologic properties of a watershed in the taiga where permafrost is present. Even though the total area of Dingman's study was only 1.79 km^2, it appears to be representative of much of the low-to-moderate elevations of the taiga with respect to vegetation, permafrost, climate, and soils. His general conclusions should apply to a much larger area. Winter data were not collected during the four years of the project.

Dingman prepared a detailed topographic map of Glenn Creek on which he delineated vegetation patterns and permafrost boundaries and concluded that these two have a close correspondence. Also, he calculated equivalent latitudes (to be discussed later) for the watershed, concluding that permafrost and equivalent latitudes were closely correlated. Where calculated equivalent latitude was greater than 65%, permafrost was likely to be present, and where less than 60%, permafrost was absent. Of the four summers included in Dingman's work (1964-67), 1964 was considered "normal" and his analysis showed that about one-half of the summer's precipitation was returned to the atmosphere by evapotranspiration. This is considerably less than had been calculated by

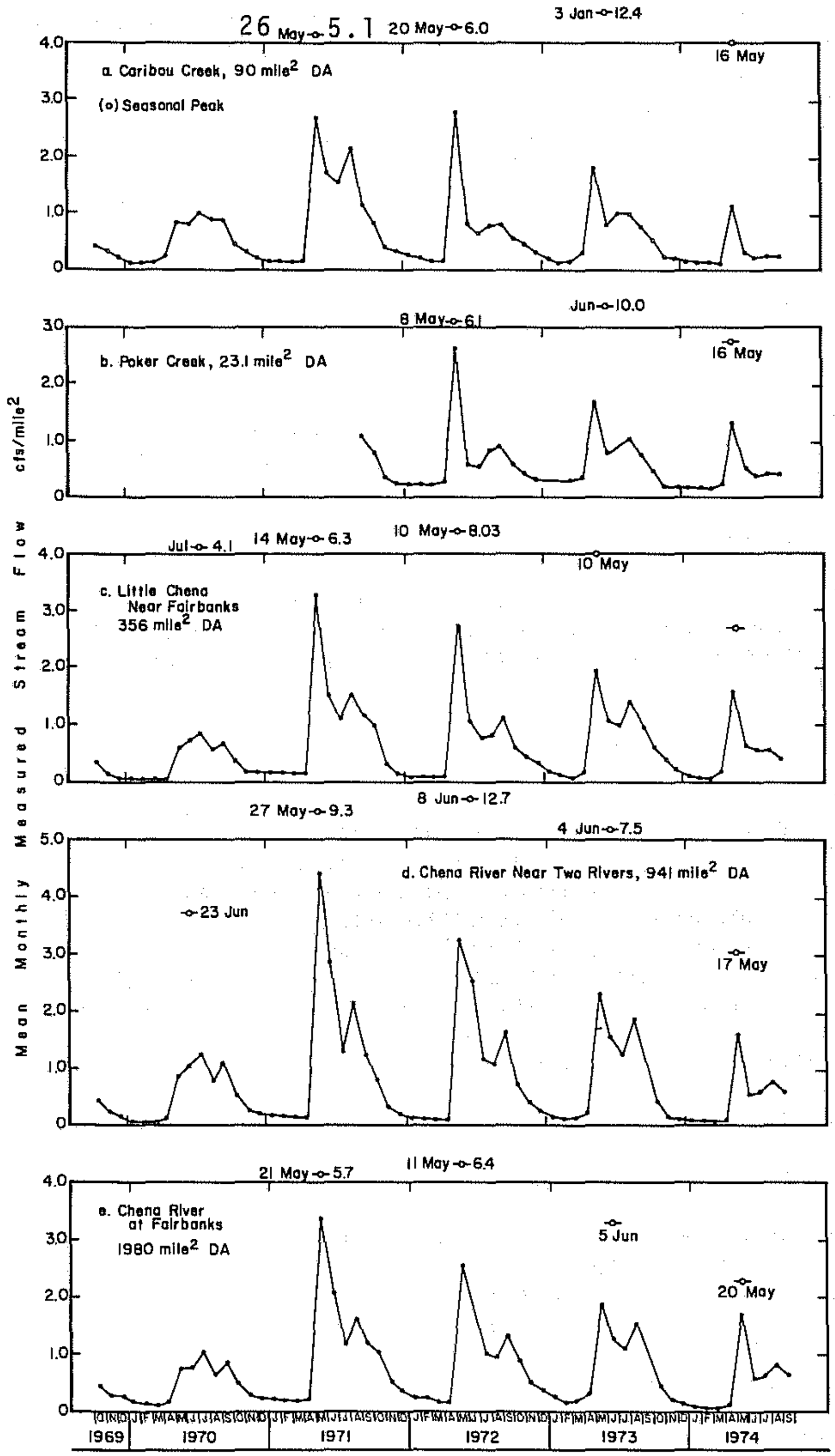

Figure 24. Comparison of monthly hydrographs of Caribou and Poker creeks with nearby rivers.

others and was only 31% of potential transpiration. Stream response to storms was rapid and the duration of hydrograph rise was essentially equal to that of the storm; lag time for runoff was not significantly related to antecedent discharge. This led Dingman to conclude that surface runoff from the valley bottom was the dominant source of streamflow during a hydrograph rise. Hydrograph recessions for 12 storms were extremely long compared to those of temperate regions; this he ascribed to the lower evapotranspiration rates in Glenn Creek and to the delay in the flow of water on the mineral soil beneath the thick moss cover. Dingman's work was the first to make actual measurements of rainfall and runoff to get an estimate of water balance in a taiga watershed of Alaska. His conclusions can reasonably be extended to the Caribou-Poker Creeks Research Watershed, since both have similar terrain and are located only 16-24 km apart.

Precipitation-runoff relationships for watersheds become important when only time and amount of precipitation are known. Such an analysis was done by Ford (1973) for part of the Caribou-Poker Creeks Research Watershed. His approach was essentially the same as that of Dingman, (1971) but the watershed areas were about thirteen times as large as Glenn Creek, making it more representative. Total area of the Caribou Creek basin analyzed by Ford totaled 24.3 km^2. It contains three major first order tributary basins (C-1, C-2, C-3) as well as slope area that contributes to the Caribou Creek main stream below the primary tributary basins but above the Caribou Creek gaging station.

Ford used precipitation data from three Belfort weighing recording gages: one in Caribou Creek valley (elevation 256 m); one in C-2 at an elevation of 640 m; and one in C-3 at 640 m. Each was equipped with drum chart recorder to permit weekly records of hourly and daily rainfall. Because one gage was in a valley site which comprised only 19% of the total area of the watershed, Ford calculated a weighting factor to balance the contribution of measured catch at a gage to the total catch on the watershed; from this he estimated total catch when one or more gages were not functioning during a given storm event. Standard eight-inch nonrecording rain gages were placed near the recording gages as cumulative checks for the weekly records.

Daily and hourly discharge data were used to construct a hydrograph showing time-discharge relationships for selected storm events. Ford utilized discharge and precipitation data from June through August of 1970 and 1971. Precipitation during this three-month period was 21.8 cm in 1970 and 23.4 cm for 1971. Snowfall at Fairbanks (about 40 km distant) showed a near record minimum for the 1969-70 winter compared to a record high the next winter when more than 3.66 m of snow fell. These snowfalls are also reflected in Caribou Creek runoff; only 8,388 ha-m was measured during the spring runoff until the first major storm event in June. In 1971, with its record snowpack, 254,348 ha-m was measured before a major storm occurred in June.

Ford's (1973) analysis showed a response time of about 2 hours from the beginning of summer precipitation until the hydrograph rises and that the rise continues through the storm event. The rising limb of the hydrograph is steep but the recession limb tails off much longer than has been reported for temperate regions. A similar rise and fall was noted by Dingman (1971). Ford suggested that this rapid response time was caused by a near-channel source of overland flow and that storm runoff is from a stable source. Moreover, the percentage of storm rainfall becoming runoff was nearly constant for all sizes of storm studied. This suggests that discharge is not significantly influenced by antecedent moisture and leads to the hypothesis that runoff processes in Caribou are stable and relatively independent of antecedent moisture.

The long recession time contributes to a high level of baseflow, explained by the long retention time of the thick moss layers on north slopes and valley bottoms. The recession factor calculated by Ford (1973) is much smaller than those reported for watersheds in humid to subhumid climates; this is believed caused by the water-holding properties of the thick moss layer that acts to detain water on long slopes, thereby causing a higher base flow than would be expected compared to more temperate regions. In examining the precipitation records from the three stations, Ford (1973) noted that there was no pronounced orographic effect though the catch in C-3 was slightly higher than either of the other two. He found a good correlation between calculated and observed runoff using his calculated hydrograph obtained from a recession equation. This led him to conclude that, having an average recession constant, runoff could be calculated from precipitation amounts and hourly discharge. Such a tool could be useful in predicting runoff from the low order streams contributing to the upper reaches of large basins in the taiga.

Ford (1973) offered four recommendations for future efforts dealing with the hydrology of these and other similar basins. (1) Obtain greater continuity of data—he suggested monthly recording to ease the logistical load of chart changing. (2) The precipitation network should be altered to obtain more uniform coverage, e.g., a reference gage at the stream gaging site with four others placed in quadrants to represent 4.6 km^2, each with the reference gage representing the valley bottom. Such a network assumes the absence of a pronounced orographic effect. (3) More information is needed on evapotranspiration in Alaska to assist in understanding the anomalous recessions compared to basins under study in the conterminous states. A similar conclusion was reached by Dingman (1971). (4) The responsibility for network installation and data collection should be that of the individual researcher. It is a definite handicap when only raw data are handed an investigator without knowing the method of collection or reliability of such data. Ford gives this last recommendation highest priority.

The value of the work reported here outweighs the apparently limited magnitude of these effects because, for the first time, some insight into the functioning of first and second order watersheds in the taiga was acquired. Moreover, several factors influencing precipitation runoff relationships were different than expected, based on similar work done in temperate regions. It would appear that vegetation, chiefly the thick moss layer, is the dominant factor in controlling hydrologic response to storm events, base flow, and hydrograph recession. Base flow was higher than for similar streams elsewhere and recession limbs of the hydrograph are longer. Both are attributed to the retention and slow, continuous release of water by the moss layer. Hydrographic response is independent of antecedent moisture and is more rapid than that reported from temperate regions. This is probably caused by overland movement of water from a constant area during a storm event. No pronounced orographic effect on precipitation was noted; however, this needs validating by more extensive gaging.

Despite the value of these findings, two years' data are insufficient to predict the hydrologic behavior of taiga watersheds. Discharge and precipitation monitoring should continue and the precipitation network should be enlarged to include Poker basin so that a similar analysis can be done for the entire watershed. Discharge records are needed for both Caribou and Poker creeks' main streams to adequately describe the hydrologic functioning of the total watershed as a unit. An additional effort that is badly needed is continuous discharge measurements during winter conditions for the main streams and, ultimately, for each individual subbasin.

PERMAFROST

The presence of perenially frozen ground in taiga watersheds is a distinguishing feature and an additional hydrologic factor to be considered in watershed research. Permafrost may simply be considered as earth material which remains continuously frozen for two or more years. Engineering problems associated with permafrost are influenced both by the nature of those earth materials and by the freezing/thawing processes. Water content and drainage are important factors in permafrost stabilization. Dry gravels or bedrock, even though frozen, do not generally pose serious engineering problems whereas, at the other extreme, saturated silts or clays can have severe stability problems when thawed. The point here is that permafrost as a factor in watershed research must be considered, not only as a substance, but in terms of the phase change process (freeze-thaw) acting on normal geologic materials. Thus, some knowledge of how earth materials behave in the unfrozen and frozen state is essential.

Permafrost may be classified as continuous (occurring under all terrains), discontinuous (occurring under certain terrains), and sporadic (occurring as occasional frozen inclusions, not directly related to the present environment). Permafrost thickness ranges from zero at the southern extreme to more than 600 m in northern Alaska. Permafrost temperature may range from -0.5 to -15°C; temperature is an important factor determining stability of engineering works where permafrost occurs. Permafrost influences plant life, surface water runoff, and groundwater movement. The mere presence of permafrost is an indication that the substrate is cold, and even when the "active layer" (surficial zone of seasonal thaw) thaws in summer, soils remain too cold for optimum plant growth.

Caribou-Poker Creeks Research Watershed lies in the zone of discontinuous permafrost. North-facing slopes and valley floors generally are underlain by frozen ground, while south-facing slopes and ridge tops are free from permafrost. General permafrost distribution in the basin is given in Figure 25; the areas with permafrost are listed in Table 1.

Permafrost acts as an impermeable layer in soils, preventing water from percolating into the deeper soil horizons; this presumably should result in increased rates of runoff (compared with permafrost-free slopes). Presence of a thick moss layer generally precludes drastically accelerated runoff and associated soil erosion where permafrost is present. The active layer over permafrost may be very thin (1.2-2 m) because of the insulating qualities of the ubiquitous moss layer.

Because of impermeability of the frozen layer deeper in the soil, the active layer remains saturated when it thaws. If the vegetation cover is removed, this saturated layer may slide or even flow on moderately steep slopes, although the percentage of silt and clay is low. This process may expose new frozen layers which in turn slide downslope. If relief is gentle, physical soil erosion may be minimal but the total volume of the substrate may be reduced through thaw and consolidation, resulting in an undulating topography called a thermokarst. Thus we see the interaction of plant cover, slope, and soils as controlling factors in permafrost terrain degradation.

Permafrost on slopes can also prevent water which has infiltrated unfrozen soil, high on ridges and upper slopes, from coming to the surface as it moves downslope under the influence of gravity. Such confined groundwater would be under a gravitational pressure head, and can produce artesian wells if the permafrost is pierced, as by well drilling. Depending on the thickness of permafrost, water under pressure might migrate across narrow valleys and issue through unfrozen soils as springs. In such cases, the impermeable permafrost acts as an aquiclude and allows groundwater, recharged high on slopes, to migrate far from its origin and appear as perennial seeps to allow constant streamflow during summer and winter months in the absence of rainfall.

Another manifestation of groundwater movement under permafrost is the occurrence of pingos, of which there are several in the Caribou-Poker creeks catchment. Pingos are conical mounds of nearly pure ice, believed to be formed when confined (under pressure) groundwater flows upward through an unfrozen zone, then freezing when colder temperatures are encountered. Such mounds are usually found on north-facing slopes near the valley bottom, and have a thin veneer of soil on which trees are growing. These trees frequently tip outward from the center of the pingo, indicating that the ice is growing. Pingos have a discrete life; they ultimately thaw, often with a small pond forming in the void formerly filled with ice. At least one pingo in the early melting stage is found in Caribou Creek basin (Figures 26 and 27). Pingos are believed to have formed under a colder climate than at present; they wane when the supply of groundwater is cut off or a warmer climate causes thawing to exceed freezing.

Dingman (1971) applied the concept of "equivalent latitudes," an index of incoming solar radiation, to the presence or absence of permafrost. Equivalent latitude (Θ) is a concept that attempts to equate potential insolation to measurable landscape variables. These include: degree of slope; azimuth of slope along the fall line; and actual latitude (which is a measure of the sun's altitude at its zenith). In the

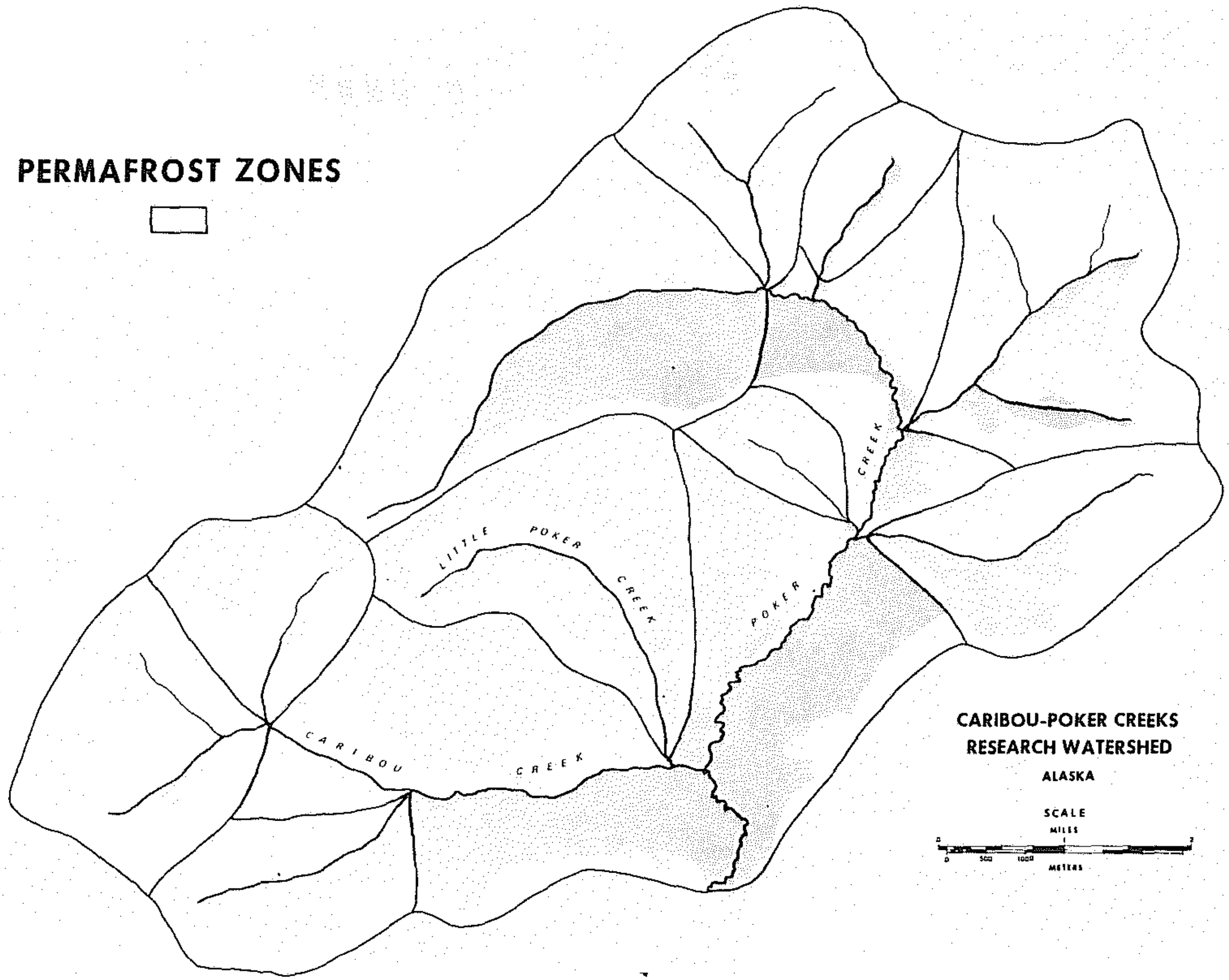

Figure 25. Distribution of permafrost in the research watershed; note the relationship to topography in Figure 2.

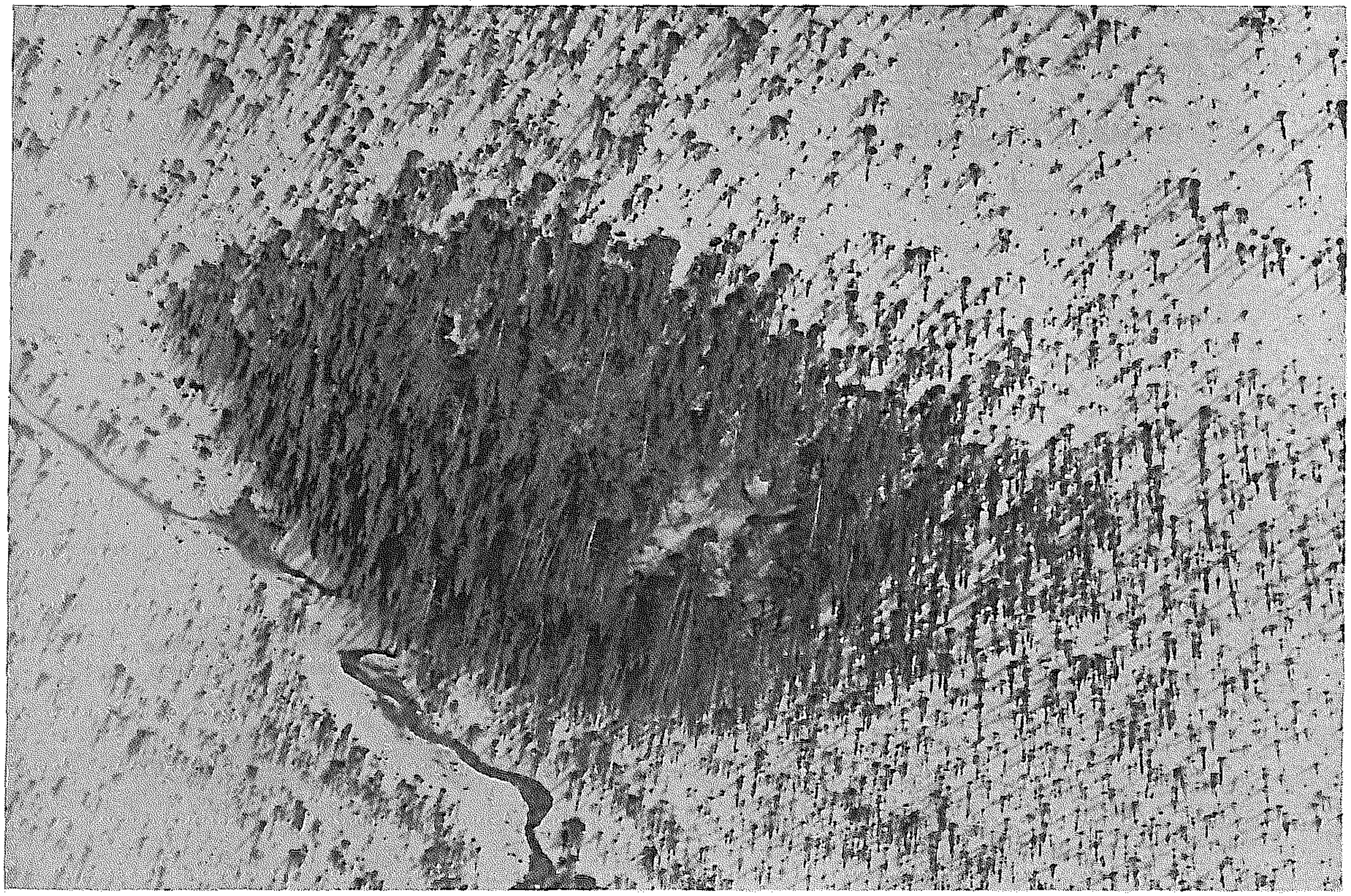

Figure 26. A mature pingo in Caribou basin. Note the increased density of spruce (probably black) on the mound.

Figure 27. A waning pingo with a small pond near its center, also in Caribou basin. Such a pingo will continue to melt, finally leaving a pond as the cycle is completed.

Glenn Creek basin (at Fox, Alaska), he found a good correlation between presence of permafrost and calculated equivalent latitudes. Dingman found permafrost where Θ exceeded 65^{0} and no Θ was less than 60^{0}. Koutz and Slaughter (1973) described these principles briefly, and developed a simple computer program using these three variables. Although potential insolation and equivalent latitude (Θ) are not strictly linearly related from the equator to the poles, between 20^{0} and 70^{0} the regression is approximately a straight line, and thus applies in the latitude of Caribou-Poker Creek Research Watershed. Koutz and Slaughter (1973) applied this principle to the Caribou-Poker creeks catchment and constructed an equivalent latitude map of the entire basin.

The calculated values for Θ ranged from 50^{0} to 80^{0} for the entire basin and the contour map derived from these data illustrate where the steep gradients occur (Figure 28). Note how topography coincides within individual basins by contour spacing for Θ.

Dingman's (1971) 60^{0}-65^{0} value for permafrost delineation shows a close correspondence of permafrost presence with north slopes and valley bottoms (Θ = 70^{0} to 80^{0}), while most south slopes and ridges have values of Θ from 50^{0} to 60^{0}.

Effects of elevation, at least in the ranges within those of the Caribou-Poker basins, do not appear to be important in computing Θ. As evidence for this, subbasin P-2 has 62% of its area above 640 m, and a large proportion of its area has Θ of about 50^{0}. A similar relationship is shown for high south-facing slopes and ridge tops. Apparently, the effects of direction and degree of slope far outweigh the effects of elevation on permafrost occurrence in this setting.

Koutz and Slaughter (1973) found good but not complete correlation in applying their Θ map to vegetation and soil maps of the basin. They attribute some of this nonconformity to the base of the topographic maps used (a controlled mozaic, but 1952 photgraphy corrected for elevation--while the bases of the soils and vegetation maps were both uncontrolled aerial photographs) and to planimetric errors. They point out that Θ cannot indicate the amount of ice in a landscape, only the temperature. Moreover, even though a close correspondence was found between Θ and vegetation and soil, they do not recommend that this procedure replace other types of environmental exploratory tools. Rather, it might act as a form of map reconnaissance to precede other procedures seeking ground-temperature relationships.

ICINGS

Ice-covered streams and out-of-channel ice accumulations (icings*) are not unique to the taiga. Both may occur where temperatures drop

*A term frequently used to denote icings is "glacier" or "glaciering;" this term is unacceptable as a synonym for icings because the processes forming a glacier are totally different from those that form icings. Alternative terms for icings are "aufeis," a German term meaning surface ice, and "naled" or "nalyed," used in Russian literature. For a more complete discussion of icings and their engineering significance, the monograph by Carey (1973) is recommended.

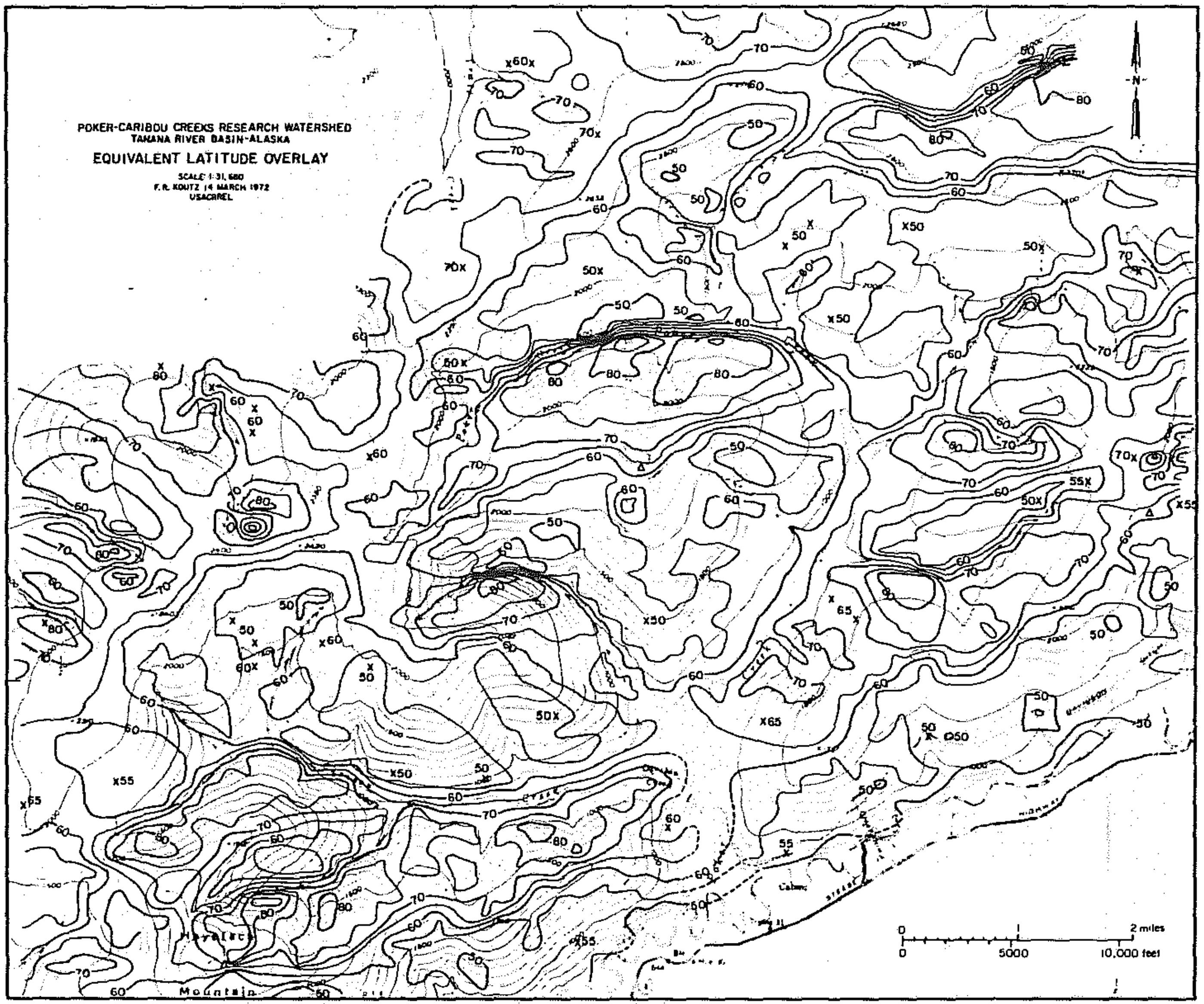

Figure 28. Equivalent latitude map showing correspondence of latitude to topographic aspect.

below freezing for a sufficient length of time to satisfy the latent heat of freezing and allow a crust of ice to form over a body of water. Icings, as used in this discussion, are not to be confused with the normal cover of ice that forms over a stream or lake in response to cold weather. Icings are formed as thin, successive sheets of ice over any surface, whether it be a stream surface, a floodplain, a roadway, or a small portion of any terrain. Icings may be caused by culvert blockages, by seepage from groundwater (springs), or in streams by diversion of surface water to above an ice cover, where it freezes in successive layers. Only stream and valley icings will be discussed here.

Water in ice-covered streams is very near freezing temperature. Our experience shows 0.2°C water is common in winter and, even at this temperature, water overflowing ice will steam when air temperatures are zero or colder (Figure 29). Icings are common in all subbasins of the Caribou-Poker creek watershed but do not occur every year; nor does each basin behave the same during a year that icings are prevalent.

Icings have been studied intermittently in these watersheds since 1969. Kane and Slaughter (1972) first started observations on accumulations of ice in subbasins C-1, C-2, and C-3 in December 1969 and continued until after breakup in 1970. They estimated total volume of ice and concluded that, for the 1969 water year, 4% of the total annual discharge and 40% of the winter streamflow were stored as ice. Most of this stored ice remained after the snowpack had melted, augmenting streamflow for about 4 weeks after normal high water from snowmelt. Ice started to accumulate in December at a nearly linear rate until it reached a maximum by March; it remained nearly static through April, and melted in May. Ice started to accumulate in the valley of subdrainage C-3 a full month earlier than in C-1 and C-2. However, the time of maximum accumulation and the maximum depth of ice (≈ 1.5 m) were similar for all three.

Although definitive causes of such extensive icings are imperfectly known, they are products of vagaries in weather elements which somehow cause icings to occur in some winters but not in others. Weather records for Fairbanks show that the winter of 1969-70 had a near-record low snowfall, with never more than 33 cm on the ground, and a prolonged cold spell in January. November lows dropped to -41°C when there was only 20 cm of snow on the ground, and although December was mild for Fairbanks, no new snow fell. The ground had only a 15 cm snow cover until January 22, after the near -40°C at the middle of the month. These generalizations suggest that one factor in icing occurrence is the combination of low air temperature and little snow accumulation during early winter (Carey, 1973).

Continuation of the icing study in Caribou Creek during the 1970-71 winter was planned, but no significant icings occurred that winter in the basin. Weather records at Fairbanks show that 1970-71 had a record snowfall, and temperatures never dropped below -31°C. Snow depth decreased to 56 cm by December 15, but increased to 102 cm by December 24, and remained above 86 cm for the remainder of the winter reaching a maximum of 109 cm early in March 1971. Despite some severe cold snaps

Figure 29. Liquid water at 42^{o}F below zero (-41^{o}C). There was slight steaming when the photo was taken; note the emission of water from the bank. Water under these conditions is a thick mixture of water and ice crystals; the thermometer stood free when released.

(down to -41°C early in December, -43°C late in December, and a prolonged spell January 9-30 when lows stayed below -34°C and dropped to -51°C), the deep snow evidently provided enough insulation to prevent extensive icings on Caribou Creek and elsewhere. These observations indicate that despite the very cold weather in January, the early snow tended to prevent icings; this reinforces statements that early, heavy snows reduce icing incidence (Carey, 1973).

The formal icing study in Caribou Creek was discontinued in 1971. Continued observations (no quantitative data) at the confluence of Caribou and Poker creeks, and elsewhere in the watershed, show that icings were limited in 1971-72, where there was a 60 cm cover by December 18 and snow cover remained deeper than 50 cm throughout the winter. This winter was not particularly severe with respect to low temperatures, although lows approached -45°C in January. Again, the early snows prevented extensive icings.

In late fall of 1972, EPA established a field laboratory at the confluence of Caribou and Poker creeks (Lotspeich et al., 1976) and weekly observations were made on the extent of icings for 1973, 1974, and 1975. The winter of 1972-73 was similar to the previous year, and ice thickness on Poker Creek never exceeded 0.8-1 m (Figure 30). Winter temperatures were mild for this region; December lows fell below -34°C only once (from January 12 through 27). However, 25 cm of snow was on the ground before the cold snap in December, and the snowpack increased to 43 cm before the cold snap in January. Thus, we have three years without icings in the watersheds, each with moderate to deep snow early in the winter before really cold weather arrived.

In 1973-74, icings at the confluence of Caribou and Poker creeks were moderate and, although covering a large area (Figure 31), were not particularly thick. Records from Fairbanks show that snowfall was light in 1973-74 with only 5 cm on the ground on November 7, which increased to 25 cm on November 11, and never became more than 33 cm in depth through January. Temperatures in November dropped to -36°C; temperatures in November and December oscillated with several lows below -29°C. A prolonged cold snap appeared during January when minimums remained below -34°C for nearly three weeks. A cold snap also occurred in February when temperatures dropped twice to nearly -45°C. Snow depth increased to 43 cm on February 16 and remained at about this depth until breakup. It would appear that a snow depth in excess of 25-30 cm is required for insulation early in a winter to prevent icings, even in the absence of severely cold temperatures. Moreover, in the absence of adequate early snow cover, later accumulations tend to increase the severity of icings (Carey, 1973).

The 1973-74 observations led to speculation on mechanisms by which icings accumulate. One observation was that although ice had been accumulating in both Caribou and Poker creeks all winter, the accumulation rate became much higher in February and March until warmer temperatures caused melting during daylight hours. This time period coincided with the increased snow depth which, in turn, led to a possible mechanism for icings to enlarge. At the time (1973-74), only Poker

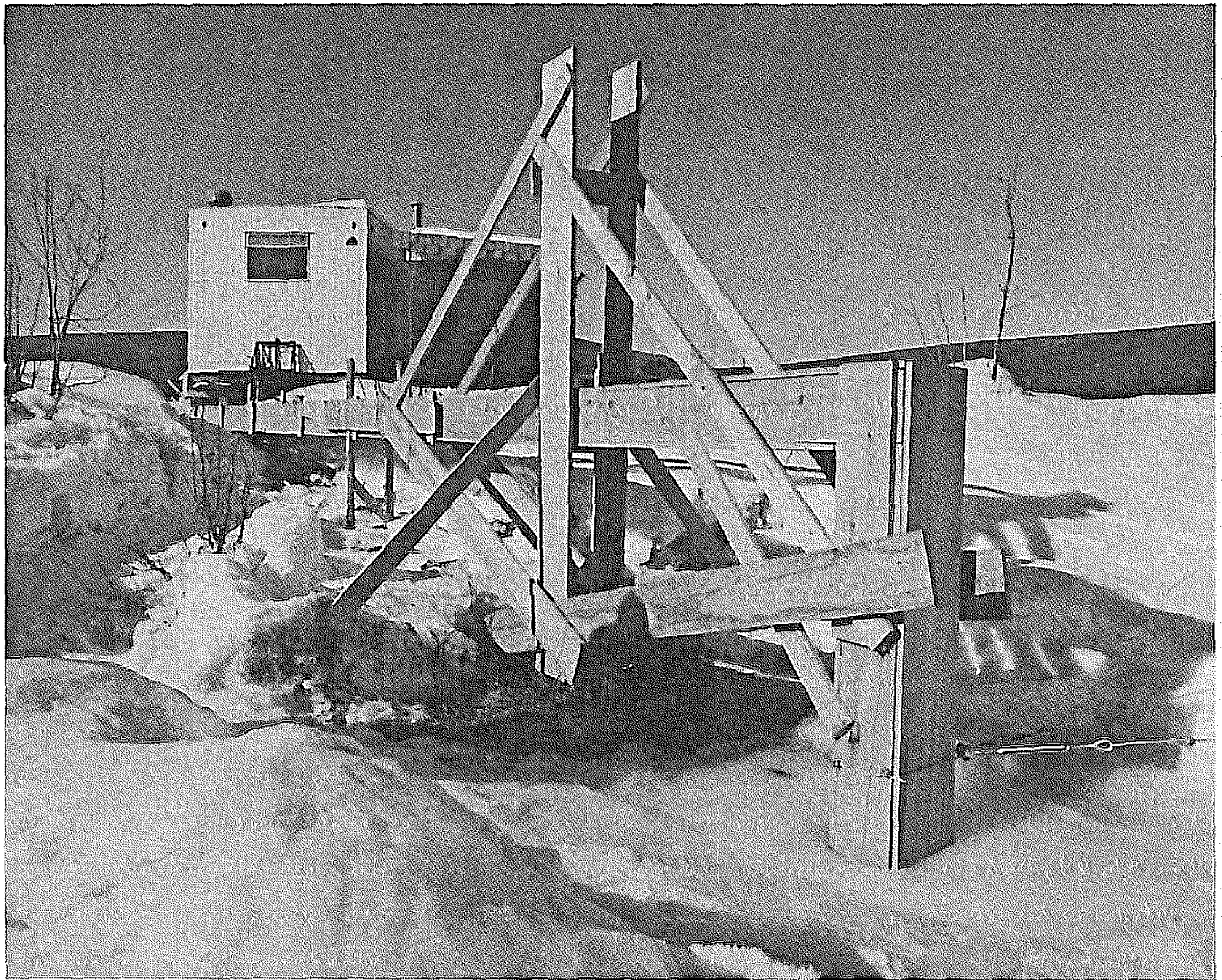

Figure 30. Poker Creek at the trailer site at the end of winter 1972-73. There was no icing during this winter; total ice thickness was 2-3 ft (60-90 cm).

Figure 31. Icing at the confluence at the end of winter of 1973-74. Contrast with Figure 30; only about 2 ft (60 cm) of the structure shown in Figure 30 is above the ice (which is about 3 m thick).

Creek was contributing to the observed icings, and it was noticed that free water was present in the snow (Figure 32) along the edges of the banks, above the ice in the channel. There was no apparent connection between this water and the water in the ice upstream. The only source was a thin sheet of water above the ice. Water within the snow was thought to migrate up the bank by "wicking," a process similar to the action of oil in the wick of a lamp. It was not unusual to walk along the bank above the ice and encounter liquid water within the snow, which was then 60 cm deep. The most rapid accumulation of ice was during late February and March. The wicking action of the deep snow is believed to be an effective mechanism for the spread of water within the snow; that snow/water matrix later froze to form an extensive sheet of ice (Figure 33). As an example of how confounding icings are and how little we know about them, it was observed on March 19, at the time of active icing at Caribou-Poker confluence, that C-1, C-2, and C-3 showed no signs of icings. However, C-4, within 0.4 km of the confluence, was actively icing during this time.

During the winter of 1974-75, sampling for water quality started in October and continued until spring breakup. Ice thickness and icing activity were noted but no attempt was made to seriously study icings. This winter was not particularly severe with respect to temperature; there were only two episodes when the minimum dropped to -40°C for short periods. Snow had accumulated to a depth of 33 cm which decreased to 20 cm late in October, followed by a gradual increase in depth until it reached 50 cm by December 1. Snow depth remained greater than 50 cm throughout the remainder of the winter. Temperatures did not dip below -34°C before snow depth was nearly 50 cm, and then for only 3 days. A short, severe cold snap occurred in early January when minimums reached -45°C for 5 days; the rest of the winter was mild. Despite the insulating snowcover and moderate early temperatures, ice at the Caribou-Poker confluence was 1.5 m thick on Poker Creek and 0.8 m thick on Caribou Creek by December 24. By February 6, ice on both creeks was 3-3.4 m thick, gradually increasing to a maximum of about 3.6 m by breakup (Figure 34). This thick ice at the confluence caused extensive icings which covered the entire flat ground in the vicinity. On the other hand, icings at C-1, C-2, and C-3 were not nearly as thick or extensive as those that occurred when Kane and Slaughter (1972) made their study. C-4 had extensive icings in this lower reach; ice appeared to be confined to the channel about 500 m above its junction with Caribou Creek. Icings for this moderate winter were severe at the Caribou-Poker creeks' confluence and came earlier than in the previous two years. Yet, icings on the tributaries of Caribou Creek were much less extensive than those of 1969-70.

As noted earlier, development of ground access to the upper reaches of Poker Creek in 1975 allowed sampling these small streams for water quality parameters at regular intervals during winter months. This permitted winter-long observations on icings--when they occur, and their areal extent in various basins. The winter of 1975-76 was notable for shallow depth of snow accumulation. Snow depth at the coldest period (December 4-10), which had minimums in the -45°C range, was only 35 cm, decreasing to 25 cm through much of January. January was mild even

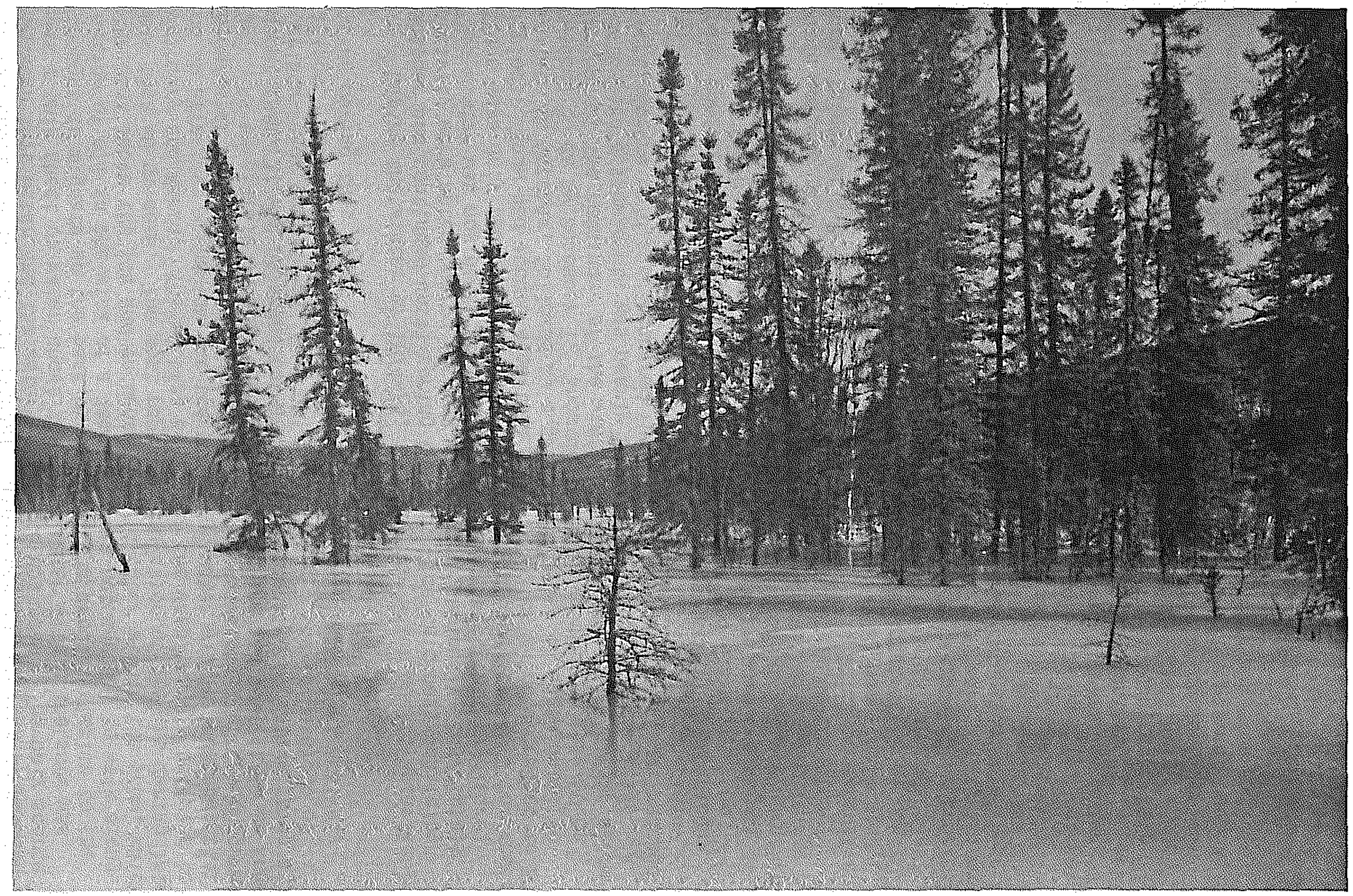

Figure 32. Development of icing as thin sheets of water flow over the ice to later freeze, at the confluence of Caribou and Poker creeks, 1974.

Figure 33. Icing in 1975 at the trailer site. This was the most severe icing experienced during the period covered by this report. Both the trailer and engine house at the left had about 20 cm of ice on their floors.

Figure 34. Maximum thickness of ice in 1975 in Poker Creek was 3-3.5 m. The ice auger shown here has four sections each about 1 m long. Water flows beneath the ice in these streams and can be sampled if the site is marked before ice accumulates.

though -40^{o}C was recorded on three days. By December 17, ice in some tributaries prevented the collection of a water sample, because the ice froze to the bottom and blocked the stream at that point, causing extensive icing upstream. By January 20, all streams had 2 m or more of ice at the observation points. At P-6 on the main stream of Poker Creek, ice was at least 3 m thick and covered an extensive area of the valley (Figure 35). Icings at P-4 and P-6 continued active for the remainder of the winter and prevented acquisition of water samples. At the upper stations, P-1 and P-2, ice accumulated to a depth of about 2 m but did not cover an appreciable area. Reasons for this restriction may be the steeper gradients at this site and the small discharge of the streams. However, all streams were icing early, apparently resulting from the thin snow cover and the early cold in November 1975.

SUMMARY OF WATERSHED FUNCTIONING

Because of problems in maintaining and servicing outdoor weather instruments during the severe winters, every effort should be made to obtain data from nearby weather stations that have general applications to the research watershed as a unit. As suggested in the section on climatology, field measurements of various weather elements should concentrate on microclimatology. If done judiciously, certain weather elements can be extrapolated from National Weather Service data at Fairbanks to the Caribou-Poker Creeks Research Watershed. This is not to imply that precipitation or temperatures will be identical but, rather, that trends in weather patterns can be forecast from Fairbanks that apply equally well for Caribou Creek. Thus, cold waves or cloudy, wet weather forecast for Fairbanks should apply to the watershed but actual numbers will be slightly different because of differences in microclimate.

Climate variability between the two locations is generally less during winter than summer because winter weather patterns are less affected by local topography. Thus, when it is cold in Fairbanks, it is cold at the watersheds and when it snows in Fairbanks, it is likely to snow in the watersheds. Summer variability is greater because topography has more control over precipitation and winds; Fairbanks, in the broad Tanana Valley, has a microclimate substantially different from that of the valleys of Cairbou-Poker Creeks Research Watershed. Examples of the trends are the low snowfall in both places in 1969-70 and record snowfall in both the next year; depths of snow were not identical but the trends were present. When extremely cold temperatures occur at Fairbanks, similar temperatures occur at the research watershed; this was validated by the data from 1969-70 when a long-lasting cold snap occurred.

Certain hydrologic factors apply equally well in both temperate areas and the taiga, if tempered by cautious judgment relating to differences caused by latitude. Geology of an area is independent of latitude; hence, it is of equal importance in the taiga as in more temperate regions. Geology important in determining landforms and water quality includes lithology, mineralogy, and geochemistry. In the taiga, certain geomorphic processes of mass wasting assume more importance than in temperate regions because of the cold. Solifluction and frost heaving are examples. Landforms and drainage patterns evolved and

Figure 35. Aerial view of Caribou-Poker creeks confluence at the end of maximum ice accumulation (1974). Poker Creek at the top, Caribou Creek at the left; both join at the trailer and flow out toward the upper right. Compare with Figure 22.

are controlled by the same factors in cold regions as in more temperate regions. Physical processes of weathering become more important than chemical processes in cold climates because of generally lower rainfall, lower temperatures, and long periods when the solvent action stops because the water is frozen.

Soils are formed by the same processes in the taiga as elsewhere. As for geomorphic processes, however, the balance of causative factors is weighted toward physical processes. Rock type and mineralogy are as important in soil development in the taiga as in temperate regions. The same ecological factors operate in the taiga as elsewhere to form vegetation patterns as a factor of soil formation. Although rates of soil development are reduced in cold regions, a definite pattern is developed, and the associated vegetation is as important an indicator of soil conditions as elsewhere. Plant communities are different, with less species diversity, but otherwise they respond to the same environmental factors. One characteristic of soil that appears to be unique to cold climates is the thicker litter layer on nonpermafrost slopes, compared to temperate forests and the ubiquitous, thick moss layer where permafrost occurs. This thicker vegetation layer is an important hydrologic factor controlling runoff, recharge, and base flow. Moreover, the large total mass of the nonmineral soil contains a large percentage of nutrients that are slowly released by mineralization in cold climates. Thus nutrients are not lost by runoff or deep percolation.

Quantitative geomorphic properties of watersheds are hydrologically as important in the taiga as in temperate areas. For the most part, the processses they control are similar. Thus, drainage area, aspect, compactness coefficient, and areas within prescribed elevation limits are important hydrologic parameters in the taiga as elsewhere. Evidence to date indicates that drainage densities in the taiga may be lower than in temperate regions under conditions of similar rainfall. Several features of the subarctic climate and vegetation combine to cause this variance; low drainage density may be one unique feature of taiga watersheds. Slope aspect assumes a more important role because of the high latitude (low sun angle) and its influence on insolation . Southerly aspects are much warmer than northerly aspects; at the latitude of Caribou-Poker creeks, permafrost is always present on north slopes and absent on south slopes. One interesting feature of high latitudes with respect to aspect, insolation and sun angle is very long summer days when direct insolation is actually received on north slopes at an oblique angle. The efficiency of this extreme day length may be the reason that only about 25% of the Caribou-Poker basin is underlain by permafrost.

Permafrost is a hydrologic factor that is unique to the taiga and the Arctic. Slopes free from permafrost behave, with respect to precipitation, much the same as elsewhere. Where permafrost occurs, it may prevent water from entering deeper soil horizons or may act as an aquiclude when water enters unfrozen soil and migrates downslope under a layer of permafrost. Precipitation that falls on impermeable soils gives rise to increased runoff with ensuing erosion. In the taiga, however, this is offset by the thick moss layer. The end result is a saturated upper zone of soil and a slow movement of water downslope. Water occluded beneath permafrost gives rise to pingos and seeps where they would not be expected based on geology alone.

Many details of the microclimate cannot be estimated by one station 40 km away; this fact justifies a climatological network in the watershed. Temperature patterns show that valleys are warmer in summer than the higher elevations. In winter the reverse is true; moderate inversions develop and ridges are several degrees warmer than valleys. Winds at valley sites are usually light and variable, whereas on the high peaks and ridges, winds blow almost constantly over a wide range of velocities from light to strong in response to the regional synoptic patterns. Summer rainfall in the watershed is generally greater than that at Fairbanks. This is probably caused by an orographic effect in the watershed compared to the broad valley in which the Fairbanks weather station is located. However, within the watershed, there does not appear to be a pronounced orographic effect in summer. One important aspect of climate, that of evapotranspiration, has not been studied in the taiga. The two works cited earlier (Dingman, 1971; Ford, 1973) based some of their conclusions on an assumed low rate of evapotranspiration in these watersheds compared to rates in more moderate climates. This area of climatology lacks reliable data and should be included in future work.

Available data for precipitation-runoff relationships in these watersheds suggest that several features of stream hydrology are at considerable variance with those found in temperate latitudes. Hydrographs for a 23 km^2 area of the Caribou Creek basin show a short lag time with a long recession limb following a storm event. This recession limb is much longer than that found in similar order streams in temperate regions, and is attributed to the thick moss layer that retains a large portion of rainfall and slowly releases it after a storm event. Baseflow in these small streams is relatively higher; this is again attributed to the moss layer with its slow release of water. Both the long recession and high base flow may be influenced by the presence of permafrost which affects permeability of surface soils and downslope movement of groundwater under a permafrost layer. These characteristics would tend to stabilize flow from low order streams and reduce flood hazards during prolonged storm events.

Extensive icings in these low order streams also tend to prolong flow recession following spring breakup. Ice stored during winter is water that will not run off as rapidly as the snow pack melts, and will slowly melt after the peak flow to augment post-breakup flow.

A major deficiency in the data base for these watersheds is the general lack of systematic winter data on streamflow, water quality, causes of icings, and soil-moisture relationships, both on and off permafrost. Another serious deficiency is the lack of knowledge concerning energy cycling and nutrient flow. Winter work in these watersheds is difficult but unless it is done, little can be said about their functioning as being representative of taiga hydrology. Physical and biological processes do not stop during the long, severe winter; they slow down or may be replaced by other processes. Aquatic life in winter may be slowed but it is not wiped out; more data on this aspect of water quality should be acquired.

Results now available document conditions in the study area, and emphasize the importance of local site and permafrost occurrence in affecting catchment functioning. Attention should now be turned to (1) more detailed study of processes operating in the various sectors of this environment, i.e., why consistent differences in water quality are observed among the various subdrainages, and (2) research into consequences of land management practices--such as timber harvesting, prescribed burning, and road building--on the complete environmental system.

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